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U.S. ARMY TACOM

APPLICATION OF COMPOSITE MATERIALS
TO TRUCK COMPONENTS:

LEAF SPRINGS AND PROPELLER
SHAFTS FOR 5-TON TRUCKS

Department of Army Contract Number DAAK 30-79-C-0146

November 1981

by EXXON ENTERPRISES MATERIALS DIVISION
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The objective of the program was to develop lightweight experimental truck components, fabricated from synthetic materials. In particular, leaf springs and propeller shafts for the 5-ton Army truck are designed using resin matrix composite materials. Both design studies and prototype fabrication and testing are included in the program.

For the leaf springs (both front and rear) a hybrid design using steel

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leaves in combination with fiberglass-epoxy leaves produced the most cost-effective solution. The propeller shaft design employed graphite-epoxy tubes with adhesively bonded steel end sleeves.

The results of the design-material trade studies are included in the report. The fabrication processes employed in making prototype parts are also included as well as the test results obtained for the prototype parts.

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SUMMARY

Exxon Enterprises Materials Division was awarded a contract by the U.S. Army Tank-Automotive Command for the design, fabrication, and testing of components for the 5-ton truck using synthetic materials. The development covered the period from October 1979 through October 1981.

Exxon Enterprises Materials Division was responsible for the design trade study for the front and rear leaf springs and the propeller shafts, the prototype fabrication, and the initial laboratory testing of the fabricated parts.

PREFACE

The work described in this report was supported by the U.S. Army Tank-Automotive Command under Contract Number DAAK 30-79-C-0146.

The contract was monitored by Mr. Avery H. Fisher; Tank Automotive Systems Laboratory, Warren, Michigan.

The project was managed for Exxon Enterprises Materials Division by Richard L. Daugherty, Manager of Engineering.

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INTRODUCTION

1.1 Introduction and Background

Composite materials are materials with high strength-to-weight and stiffness-to-weight ratios. These properties along with the advancing state-of-the-art for designing and fabrication with them and the dramatic reduction in raw material costs make their application to commercial and industrial components feasible. Weight reductions approaching 50% are achievable when replacing conventional metal structures with advanced composite structures.

These materials can benefit the Army in several ways in truck applications. Weight reductions will result in increased fuel efficiency and overall agility. This will permit larger payloads to be transported. In addition, composite truck components are potentially more reliable than metallic components because of their improved fatique and corrosion resistant properties.

Our objective was to show the feasibility of composite materials when applied to the leaf springs and propeller shafts of the Army's 5-ton truck. The first phase of the program was a material trade study to determine the weight savings possible with the composite material systems appropriate for these applications. Four factors were considered in the choice of the designs for further study: weight savings, cost, fabricability, and interchangeability of the design with currently fabricated components.

For the leaf springs, E-type fiberglass-epoxy designs offer weight savings similar to those for the graphite-epoxy systems. Cost factors, both for the raw material and the fabrication, were the deciding factors for choosing the fiberglass-epoxy design for prototype studies. The propeller shaft material trade studies showed the graphite-epoxy designs to be the most effective.

In Phase II of the program, prototypes of the fiberglass-epoxy leaf springs and graphite-epoxy propeller shafts were fabricated.

For the leaf springs, expendable tooling and an autoclave cure process were employed. Although this was a cost effective way of producing prototype components, geometric irregularities resulted. Such a method would not be used for production; therefore, these irregularities were considered acceptable for this program.

The propeller shafts were fabricated using female tooling with an internal rubber bladder to apply pressure during cure. Because of the joint necessary between the composite tube and metal end sleeves, this tooling was extensive. In prodution, filament winding could be substituted for this process.

Laboratory testing of the components was performed as the final phase of the program. Both steel and composite material leaf springs were fatique tested; the results demonstrated the fatique characteristics of the composite assemblies were similar to those of the steel assemblies. The propeller shafts were tested under the conditions established by the industry for the steel shafts. The static strength of the composite shafts was well in excess of the required load. The fatique tests showed the joint between the composite tube and the steel sleeves failed after several thousand cycles; steel shafts fail after 75,000 - 100,000 cycles. These test results are to be related to actual requirements in field tests to be performed by TACOM.

This report presents the results of the program performed by EEMD. To establish the design properties for the composite materials considered appropriate for leaf springs and propeller shafts, a test program for E-type fiberglass-epoxy and high-strength graphite-epoxy systems was performed. The results are given in Section 2. The design study results, including the material trade studies and final designs, are given in Section 3. The fabrication processes used for producing the prototype parts are discussed in Section 4, while the test results for the component testing are discussed in Section 5. Finally, budgetary cost estimates for production of these components are presented in Section 6.

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COMPOSITE MATERIAL PROPERTIES

The material trade off studies, presented in Section 3, show that E-type fiberglass-epoxy and high-strength graphite-epoxy are the material systems appropriate for leaf springs and propeller shafts, respectively, for the 5-ton truck components. In this Section, the results of the material property testing program for these systems are presented. Also presented are the test results for the adhesives considered for the joint between the composite tube and steel end sleeves for the shafts.

The following tests were performed on unidirectional laminates for each material system.

a. Tensile test per ASTM D3039; properties were determined in both the fiber and transverse to fiber directions.

b. Flexural test per ASTM D790 with a 32:1 span to depth ratio.

c. Shear test per ASTM D2733; performed at 50°C.

d. Shear test per ASTM D2344; performed at room temperature (RT).

e. Impact test per ASTM D256, Method A (Izod).

2.1 Graphite-Epoxy Systems

Two high-strength graphite-epoxy systems were tested:

-Fiberite HyE 1048 AlE, with Union Carbide Thornel 300 fiber.

-Hercules AS/1904, with Hercules AS-4 fiber.

The results are presented in Tables 1 and 2. The HyE 1048 system was chosen for the prototype studies because of EEMD's processing experience with it; both systems exhibit similar mechanical properties.

2.2 Fiberglass-Epoxy Systems

Two E-type fiberglass-epoxy systems were tested:

-3M SP-250 E

-U.S. Polymeric EF-7172

The results are presented in Tables 3 and 4. The 3M SP-250 system was chosen for the prototype studies because of its superior properties and EEMD's processing experience with it.

2.3 Adhesives

The propeller shaft designs incorporate metallic end sleeves; the shaft end fittings are welded to these end sleeves. To allow for interchangeability of the composite shafts with the present metallic shafts, the end sleeves were fabricated from the metal tube presently used.

The fabrication process for the composite tubes incorporates an adhesive joint with the end sleeves formed during cure of the tube. Four adhesive systems were tested to determine the most appropriate adhesive for this application:

- 3M AF13
- Hysol EA9628
- Metlbond 1133
- Cyanamid FM-73M

The selected process included contacting each major adhesive company, explaining the application, and allowing them to select the best adhesive from their line. Only standard products were considered appropriate. This process resulted in the list shown above.

The results of lap shear tests, in which high-strength graphite-epoxy was bonded to steel, are given in Table 5. The test procedure was in accordance with ASTM D1002.

The results showed Metlbond 1133 to be the choice from shear strength considerations; it is also the one with which EEMD has the most experience. Therefore, Metlbond 1133 was used in the prototype fabrication program.

Table 1
Material Properties for HyE 1048 AlE

(a) TENSILE - FIBER DIRECTION

Specimen No.	Specimen Dimensions Width, in.	Thickness, in.	Maximum Load, lbs	Ultimate Strength, psi	Modulus, msi
1	0.500	0.0430	5908	274,800	21.9
2	0.500	0.0440	5820	264,600	21.9
3	0.499	0.0430	5897	274,800	21.2
4	0.500	0.0413	5401	261,600	21.5
5	0.501	0.0450	5953	264,000	21.3
Average				268,000	21.6
Std. Dev.				6,400	0.3

(b) TENSILE - TRANSVERSE-TO-FIBER DIRECTION

Specimen No.	Specimen Dimensions Width, in.	Thickness, in.	Maximum Load, lbs	Ultimate Strength, psi	Modulus, msi
1	1.000	0.0545	326	5,990	1.34
2	0.999	0.0546	349	6,410	1.32
3	0.999	0.0544	430	7,910	1.28
4	0.997	0.0548	355	6,500	1.32
5	1.001	0.0546	337	6,170	1.35
Average				6,600	1.32
Std. Dev.				800	0.03

(c) FLEXURAL

Specimen No.	Specimen Dimensions Width, in.	Thickness, in.	Maximum Load, lbs	Ultimate Strength, psi	Modulus, msi
1	1.001	0.0945	410	204,000	18.0
2	1.001	0.0927	408	211,000	18.0
3	1.002	0.0925	452	234,000	18.3
4	1.002	0.9003	373	205,000	17.3
5	1.007	0.0927	408	209,000	18.5
Average				213,000	18.0
Std. Dev.				12,300	0.5

(d) IMPACT (Izod)

Specimen No.	Specimen Dimensions Width, in.	Length, in.	Load lbs	S ft-lbs/in.
1	0.0895	2.50	4.40	*
2	0.0900	2.50	2.20	24.4
3	0.0929	2.50	2.14	23.0
4	0.0924	2.50	2.45	26.5
5	0.0906	2.50	1.62	17.9
Average				>23.0
Std. Dev.				3.7

*Incomplete Break

(e) SHEAR STRENGTH AT 50°C

Specimen No.	Specimen Dimensions Width, in.	Area, in2	Maximum Load, lbs	Strength psi
1	0.999	0.487	1239	2,550
2	1.000	0.504	1246	2,470
3	0.999	0.503	1164	2,320
Average				2,450
Std. Dev.				120

(f) SHEAR STRENGTH AT ROOM TEMPERATURE

Specimen No.	Specimen Dimensions Width, in.	Thickness, in.	Maximum Load, lbs	Strength psi
1	0.250	0.130	534	12,310
2	0.250	0.130	551	12,720
3	0.251	0.126	525	12,440
4	0.251	0.126	513	12,160
5	0.251	0.126	540	12,810
Average				12,500
Std. Dev.				300

Table 2
Material Properties for AS/1904

(a) TENSILE - FIBER DIRECTION

Specimen No.	Specimen Dimensions Width, in.	Thickness, in.	Maximum Load, lbs	Ultimate Strength, psi	Modulus, msi
1	0.498	0.0309	3825	248,600	19.6
2	0.498	0.0302	3858	256,500	19.9
3	0.497	0.0308	3649	238,400	19.7
4	0.497	0.0307	4057	265,900	19.5
5	0.497	0.0310	3860	250,600	18.7
Average				252,000	19.5
Std. Dev.				10,200	0.5

(b) TENSILE - TRANSVERSE-TO-FIBER DIRECTION

Specimen No.	Specimen Dimensions Width, in.	Thickness, in.	Maximum Load, lbs	Ultimate Strength, psi	Modulus, msi
1	1.011	0.0390	288	7,370	3.86
2	1.006	0.0398	358	8,950	3.92
3	1.002	0.0400	335	8,360	3.77
4	0.999	0.0398	316	7,940	3.45
5	0.999	0.0397	380	9,570	3.76
Average				8,400	3.75
Std. Dev.				900	0.18

(c) FLEXURAL

Specimen No.	Specimen Dimensions Width, in.	Thickness, in.	Maximum Load, lbs	Ultimate Strength, psi	Modulus, msi
1	0.999	0.0840	400	226,000	17.5
2	1.000	0.0810	419	255,000	17.2
3	1.001	0.0835	382	218,000	16.7
4	1.001	0.0822	430	254,000	17.3
5	1.001	0.0853	416	228,000	16.5
Average				236,000	17.0
Std. Dev.				17,000	0.4

(d) IMPACT (Izod)

Specimen No.	Specimen Dimensions Width, in.	Length, in.	Load lbs	S ft-lbs/in.
1	0.0810	2.50	2.65	32.7
2	0.0805	2.50	3.30	41.0
3	0.0807	2.50	2.18	27.0
4	0.0810	2.50	2.20	27.2
5	0.0802	2.50	2.20	*
Average				>32.0
Std. Dev.				6.6

*Incomplete Break

(e) SHEAR STRENGTH AT 50°C

Specimen No.	Specimen Dimensions Width, in.	Area, in2	Maximum Load, lbs	Strength psi
1	1.002	0.477	1318	2,760
2	0.999	0.471	1279	2,720
3	1.003	0.473	1182	2,490
Average				2,660
Std. Dev.				150

(f) SHEAR STRENGTH AT ROOM TEMPERATURE

Specimen No.	Specimen Dimensions Width, in.	Thickness, in.	Maximum Load, lbs	Strength psi
1	0.250	0.114	557	14,620
2	0.250	0.114	562	14,740
3	0.250	0.115	571	14,950
4	0.250	0.114	556	14,600
5	0.250	0.115	546	14,280
Average				14,600
Std. Dev.				200

Table 3
Material Properties for EF 7172

(a) TENSILE - FIBER DIRECTION

Specimen No.	Specimen Dimensions Width, in.	Thickness, in.	Maximum Load, lbs	Ultimate Strength, psi	Modulus, msi
1	0.496	0.0335	2822	169,800	6.34
2	0.496	0.0323	2646	165,200	6.34
3	0.495	0.0319	2579	163,300	6.34
Average				166,100	6.34
Std. Dev.				3,300	

(b) TENSILE - TRANSVERSE-TO-FIBER DIRECTION

Specimen No.	Specimen Dimensions Width, in.	Thickness, in.	Maximum Load, lbs	Ultimate Strength, psi	Modulus, msi
1	1.001	0.0658	318	4,820	1.88
2	0.993	0.0658	299	4,570	1.88
3	1.001	0.0636	295	4,640	1.86
Average				4,680	1.87
Std. Dev.				130	0.01

(c) FLEXURAL

Specimen No.	Specimen Dimensions Width, in.	Thickness, in.	Maximum Load, lbs	Ultimate Strength, psi	Modulus, msi
1	1.001	0.106	428	190,000	6.49
2	1.001	0.100	358	178,000	6.33
3	1.001	0.105	417	185,000	6.47
Average				184,300	6.43
Std. Dev.				6,000	.09

(d) IMPACT (Izod)

Specimen No.	Specimen Dimensions Width, in.	Length, in.	Load lbs	S ft-lbs/in.
1	0.104	2.500	8.15	*
2	0.099	2.500	8.10	81.72
3	0.1037	2.500	7.05	68.45
4	0.105	2.500	7.15	68.10
Average				>72.76
Std. Dev.				7.76

*No Break

(e) SHEAR STRENGTH AT 50°C

Specimen No.	Specimen Dimensions Width, in.	Area, in2	Maximum Load, lbs	Strength psi
1	1.001	0.505	1120	2,220
2	1.001	0.482	1186	2,460
3	1.001	0.488	1248	2,550
Average				2,410
Std. Dev.				170

(f) SHEAR STRENGTH AT ROOM TEMPERATURE

Specimen No.	Specimen Dimensions Width, in.	Thickness, in.	Maximum Load, lbs	Strength psi
1	0.251	0.102	269	7,850
2	0.251	0.103	282	8,200
3	0.251	0.104	245	7,020
4	0.251	0.104	284	8,140
5	0.251	0.105	270	7,690
Average				7,780
Std. Dev.				470

Table 4
Material Properties for 3M-SP250

(a) TENSILE - FIBER DIRECTION

Specimen No.	Specimen Dimensions Width, in.	Thickness, in.	Maximum Load, lbs	Ultimate Strength, psi	Modulus, msi
1	0.498	0.0335	3164	189,600	6.74
2	0.497	0.0333	2998	181,200	6.74
3	0.497	0.0328	3087	189,300	6.67
Average				186,700	6.72
Std. Dev.				4,800	0.04

(b) TENSILE - TRANSVERSE-TO-FIBER DIRECTION

Specimen No.	Specimen Dimensions Width, in.	Thickness, in.	Maximum Load, lbs	Ultimate Strength, psi	Modulus, msi
1	0.998	0.0400	234	5,850	2.33
2	0.999	0.0393	260	6,630	2.31
3	1.000	0.0390	288	7,380	2.44
Average				6,200	2.36
Std. Dev.				770	0.07

(c) FLEXURAL

Specimen No.	Specimen Dimensions Width, in.	Thickness, in.	Maximum Load, lbs	Ultimate Strength, psi	Modulus, msi
1	1.000	0.0725	309	202,500	6.86
2	1.000	0.0729	306	198,900	6.60
3	1.000	0.0717	293	196,800	6.61
4	1.000	0.0715	298	200,800	6.74
5	1.000	0.0718	291	194,700	6.62
Average				198,700	6.69
Std. Dev.				3,100	.23

(d) IMPACT (Izod)

Specimen No.	Specimen Dimensions Width, in.	Length, in.	Load lbs	S ft-lbs/in.
1	0.1015	2.500	8.1	79.8
2	0.1015	2.500	-	*
3	0.1011	2.500	8.2	80.1
4	0.1008	2.500	7.8	77.4
5	0.1004	2.500	7.3	72.7
Average				>77.5
Std. Dev.				3.4

*No Break

(e) SHEAR STRENGTH AT 50°C

Specimen No.	Specimen Dimensions Width, in.	Area, in2	Maximum Load, lbs	Strength psi
1	1.000	0.509	1312	2,580
2	1.000	0.512	1312	2,560
3	0.999	0.497	1310	2,640
Average				2,590
Std. Dev.				40

(f) SHEAR STRENGTH AT ROOM TEMPERATURE

Specimen No.	Specimen Dimensions Width, in.	Thickness, in.	Maximum Load, lbs	Strength psi
1	0.250	0.129	459	10,630
2	0.250	0.128	474	11,130
3	0.251	0.132	441	10,020
4	0.251	0.130	483	11,120
5	0.251	0.129	446	10,310
Average				10,640
Std. Dev.				490

Table 5
Adhesive Properties:
Lap Shear for High-Strength
Graphite-Epoxy Bonded to Steel

Adhesive System	Specimen No.	Specimen Dimensions Width, in.	Length, in.	Maximum Load, lbs	Average Shear Strength, psi
3MAF13	1	0.978	0.984	3516	3,650
	2	0.984	1.008	3593	3,620
	3	0.995	1.021	3715	3,660
	4	0.983	1.007	2660	2,700
	Average				3,410
	Std. Dev.				470
Hysol EA9628	1	0.987	1.009	1279	1,280
	2	0.973	0.996	4089	4,220
	3	0.995	1.016	3373	3,340
	4	0.951	0.969	1764	1,850
	Average				2,670
	Std. Dev.				1,490
Metlbond 1133	1	0.991	1.025	2557	2,520
	2	0.983	1.007	4221	4,260
	3	0.988	1.018	3593	3,570
	4	0.985	1.013	4101	4,110
	Average				3,620
	Std. Dev.				790

Adhesive System	Specimen No.	Specimen Dimensions Width, in.	Length, in.	Maximum Load, lbs	Average Shear Strength, psi
Cyanamid FM-73M	1	0.974	1.003	2161	2,210
	2	0.927	1.034	3208	3,360
	3	0.921	1.029	2668	2,820
	4	0.937	1.008	2745	2,910
	Average				2,830
	Std. Dev.				470

3

DESIGN STUDIES

3.1 Leaf Spring Assemblies

The objective of this program was to develop lightweight experimental truck components fabricated from synthetic materials. For this prototype program, P/N 7409613 (rear spring assembly) and P/N 7411110 (front spring assembly) for the 5-ton truck were two of the chosen components.

3.1.1 Design Criteria

The general design criteria for the composite material leaf springs designs are structural integrity, 40-50+% weight savings when compared with the present parts, interchangeability of the prototype parts with the present parts, and cost. Structural integrity was the major design criteria. Since this is a prototype program, interchangeability of parts was also considered important. Cost and weight savings were considered to be of equal importance.

For both the front and rear spring assemblies the general requirements can be summarized as follows:

a. The designs are to use at least a steel main leaf to ensure structural integrity. For the front spring, this will maintain a steel spring eye in a steel leaf; it is known that the complex stress distribution in the eye area can be handled by such a design. For the rear spring, this will provide a wear surface, with the remainder of the suspension system, of known characteristics.

b. The supporting leaves shall be fiber-reinforced composite for reduced weight. Weight reductions of 50% are anticipated. Cost shall be a determining factor as to which fiber-reinforced composite is chosen for the final design.

c. Areas of the composite leaves that contact other materials shall be suitably protected from stress risers due to cutting, abrasion, heat build-up and/or indentation which might result in premature failure.

d. The design shall be interchangeable with the present steel multi-leaf designs without modification to suspension components. For the rear spring this implies that two steel leaves be maintained because of the dimensional envelope restraints of the brackets.

e. Means shall be provided for leaf alinement to simplify installation and to prevent dislocation in service.

f. Present production frame height should not be altered.

The performance requirements to be met by each spring assembly are as follows:

Rear Spring Assembly

a. The rated load capacity shall be 15,810 pounds at the spring pad.

b. The unclamped spring rate at the rated load capacity shall be 5,983 pounds per inch.

c. The design shall be capable of withstanding the following maximum in service loads:

(1) Vertical Load - 2g (rated load + 1g = 31,620 pounds)

(2) Transverse Load - 0.75g (11,850 pounds)

Front Spring assembly

a. The rated load capacity shall be 5,560 pounds at the spring pad.

b. The unclamped spring rate at the rated load capacity shall be 2,780 pounds per inch.

c. The design shall be capable of withstanding the following maximum in service loads:

(1) Vertical Load - 2g (rated load + 1g = 11,120 pounds)

(2) Transverse Load - 0.75g (4,170 pounds)

(3) Longitudinal Load - 0.8g (4,448 pounds)

d. The design shall withstand acceleration and braking windup torques of 39,817 inch-pounds at the axle seat.

Both Assemblies

a. The design shall be capable of sustaining 11° of longitudinal twist from the axle seat to the eye when a 2g vertical load is applied.

b. The design shall meet the performance requirements at ambient temperatures ranging from -40°F to +160°F on a vehicle loaded to rated capacity.

c. The impact strength shall be suitable to meet life requirements.

d. Physical properties shall not deteriorate when exposed to any vehicle fluids, i.e., gasoline, diesel fuel, windshield washer fluid, transmission and axle lubes, engine oils, antifreeze, ether, freon, brake fluid, battery acids and steering fluid.

e. The design shall be suitably protected from excessive heat build-up due to internal friction, interleaf friction and/or accumulation of foreign matter such as mud, stones, dust or salt.

f. The design shall be capable of withstanding and maintaining a 150,000 pound clamp load, exerted by the U-bolts at axle seat while in service.

The spring assemblies shall be laboratory tested for static load and rate as well as undergo development fleet durability and fatique testing.

3.1.2 Trade Study

To meet the general requirements of interchangeability of the present and prototype spring assemblies, two steel leaves are maintained for both the rear and front springs.

The rear assembly must fit into brackets at the ends of the spring. These limit the total spring tip height. Since composite materials have poor shear strength, the composite leaves must all be of the same length. Thus, two steel leaves, each 54 inches long, will be employed along with composite support leaves that are 49 inches long.

The front assembly requires maintaining the present steel main leaf because of the eye area. The second steel leaf is needed because of the longitudinal load taken by the military wrap. Thus, if possible, the currently employed first and second steel leaves will be used in the new design.

For comparison purposes, both front and rear springs will be designed using the two steel leaves from the present multileaf steel designs with support leaves of:

a. graphite-epoxy
b. fiberglass-epoxy
c. a sandwich construction using graphite-epoxy faces and a fiberglass-epoxy core

These comparisons are shown in Tables 6 and 7.

For the rear spring assembly, the fiberglass-epoxy design results in the least number of leaves. It also produces a 50% weight savings. On the basis of material costs using 1980 anticipated prices:

Material System	Cost, Dollars/Pound
Steel	0.50
Fiberglass-Epoxy	7.00
Graphite-Epoxy	34.00

The three designs would have estimated material costs of:

Design of Support Leaves	For Spring Leaves: Materials Cost, Dollars	Comparative Materials Cost
Graphite-Epoxy	1778	3.49
Sandwich Construction	1054	2.07
Fiberglass-Epoxy	509	1.00 (Ref)

Thus, on the basis of materials and fabrication costs, the chosen design for the rear spring assembly is:

a. two steel leaves
b. support leaves of fiberglass-epoxy

All the front spring assembly designs have the same number of support leaves and all have a weight savings of at least 50%. The estimated material costs for the different designs are shown below:

Design of Support Leaves	For Spring Leaves: Materials Cost, Dollars	Comparative Materials Costs
Graphite-Epoxy	517	2.66
Fiberglass-Epoxy	194	1.00 (Ref)
Sandwich Construction	277	1.43

Fiberglass-epoxy support leaves are chosen on the basis of cost. Another reason for choosing fiberglass-epoxy support leaves is their damage tolerance: fiberglass-epoxy is approximately twice as good as graphite-epoxy.

Table 6

REAR SPRING ASSEMBLY

RESULTS OF MATERIALS STUDY

MATERIAL SYSTEM FOR SUPPORT LEAVES	NUMBER OF LEAVES	WEIGHT OF LEAVES, POUNDS		
		STEEL MAIN LEAVES	SUPPORT LEAVES	TOTAL
High-Strength Graphite-Epoxy	2 + 7	74.9	51.2	126.1
E-Type Fiberglass-Epoxy	2 + 5	74.9	67.4	142.3
Sandwich Construction of Graphite-Epoxy Faces and Fiberglass-Epoxy Core	2 + 8	74.9	68.5 (19.9 of graphite 48.6 of glass)	143.4
Present Steel Design	13	74.9	218.5	293.4

Table 7

FRONT SPRING ASSEMBLY

RESULTS OF MATERIALS STUDY

MATERIAL SYSTEM FOR SUPPORT LEAVES	NUMBER OF LEAVES	WEIGHT OF LEAVES, POUNDS STEEL MAIN LEAVES	SUPPORT LEAVES	TOTAL
High-Strength Graphite-Epoxy	2 + 2	48.6	14.5	63.1
E-Type Fiberglass-Epoxy	2 + 2	48.6	24.4	73.0
Sandwich Construction of Graphite-Epoxy Faces and Fiberglass-Epoxy Core	2 + 2	48.6	19.1 (4.4 of graphite 14.7 of glass)	67.7
Present Steel Design	11	48.6	100.4	149.0

3.1.3 Analysis of Composite Assemblies

a. Starting Point for Analysis of Fiberglass-Epoxy Designs

The starting point for the final design is the requirement of the vertical load to be carried by the spring. This load is to be applied to the spring 150,000 times without failure. The material system to be used is fiberglass-epoxy.

Typical fatique curves for fiberglass-epoxy are given in Figure 1. The flexural fatique properties are taken as:

Axial Modulus = 5.5 msi
Flexural Strength = 55,000 psi

This means that the material is assumed to be exposed to a maximum stress of 55,000 psi and an alternating stress of about 25,000 psi. This implies a fatique life of greater than 1,000,000 cycles, as shown in Figure 1.

The fatique shear strength is taken as 4,000 psi; the static allowable shear strength is 8,000 psi. Thus, as seen in Figure 2, the fatique life is greater than 1,000,000 cycles.

The density of fiberglass-epoxy is 0.073 pounds/inch^3.

b. Analysis of Rear Spring Assembly

The dimensions of the present steel spring are given in the TACOM drawing for P/N 7409613. For the analysis of the load distribution, the spring is taken in the flat condition. Thus, the distance from the support to the center bolt is 27.00 inches.

Because of the brackets currently used at the spring support, only the first two leaves can extend the full 54 inches. The maximum length allowable for the other leaves is 49 inches if these brackets are to be used in the redesign. Composite materials have poor fatique shear strength compared to metals. This means that all composite leaves must be of the same length if major weight penalties are not to be incurred. Therefore, two steel leaves, each spanning between the supports, will be used. The composite leaves will all be 49 inches long. The preliminary designs presented above do not include this length restriction. The fiberglass-epoxy support leaf case has been investigated with this restriction and the results are presented below.

The preliminary design with composite leaves being 49 inches long would result in a maximum flexural stress in the steel leaves of 198,000 psi. The maximum flexural stress in the multi-leaf steel design is 158,000 psi. There are three means of reducing the maximum stress in the hybrid design to 158,000 psi:

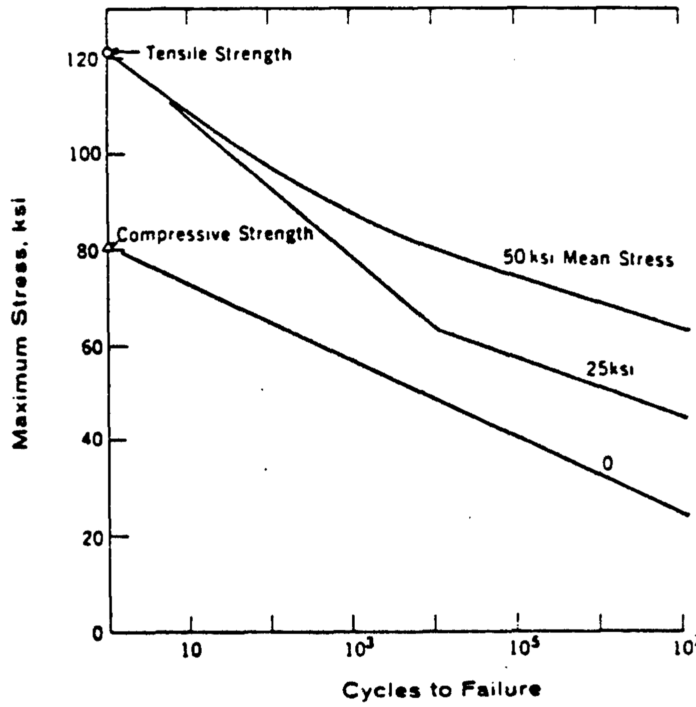


FIGURE 1 GLASS-EPOXY FLEXURAL FATIQUE RESULTS

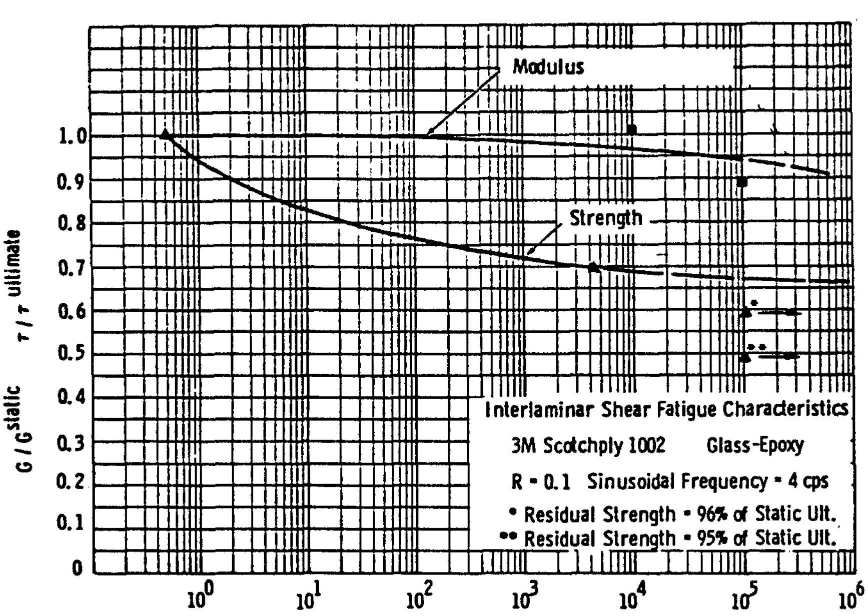


FIGURE 2 GLASS-EPOXY INTERLAMINAR SHEAR FATIQUE RESULTS

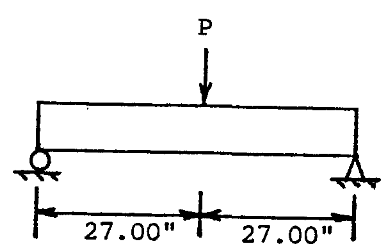
a. Reduce the thickness of the steel leaves
b. Change the initial curvature of the steel leaves so that a pre-load would negate this additional stress
c. Increase the number of support leaves

Maintaining the current steel leaves results in the highest structural integrity. To minimize weight, option b. was investigated and found to yield the required stress redistribution.

Using the 0.558-inch thick steel leaves gives the following stress analysis results:

a. Steel Main Leaf

The 0.558-inch thick present steel main leaf has a spring rate of 530 pounds/inch:



$$\delta = \frac{PL3}{48EI}$$

$$E = 30 \times 10^6 psi$$

$$I = \frac{1}{12} (4) (0.558)^3$$

where

δ = deflection under the load P

thus

P/δ = 530 pounds/inch

(2) The composite leaves, therefore, need to have a spring rate of

$$K = 5{,}983 - 2(530) = 4{,}923 \text{ pounds/inch}$$

Because the composite leaves are only 49 inches long, they must be designed to a spring rate of

$$K = 4{,}923 \left(\frac{27}{24}\right)^2 = 6{,}231 \text{ pounds/inch}$$

The length of 24 inches was chosen from considerations of the load transfer.

The portion of the vertical load carried by the steel main leaves is:

$$\text{Load in Steel Leaves} = \frac{1{,}060}{5{,}983} (31{,}620) = 5{,}602 \text{ pounds}$$

Thus, the design criteria for the composite leaves are:

$$\text{Spring rate} = 6{,}231 \text{ pounds/inch}$$
$$\text{Load} = \left(\frac{27}{24}\right) (31{,}620 - 5{,}602) = (1.13)\ [26{,}018] = 29{,}270 \text{ pounds}$$

where the factor is required because of the shorter composite leaves. Using these and the material properties in the composite program for leaf springs developed by EEMD, gives a spring assembly of two steel leaves, each 0.558 inch thick, and five fiberglass-epoxy leaves. The composite leaves are tapered with a seat thickness of 1.432 inches per leaf and a tip thickness of 0.724 inches per leaf. They are all of the same length and span. The total weight of the spring leaves is:

74.9 pounds	of steel
72.3 pounds	of fiberglass-epoxy
147.2 pounds	total

This is a 49.8% weight savings over the multileaf steel spring.

This results in a stack height for the composite spring of 8.576 inches; this is 1.322 inches more than the present steel spring. However, frame height of the vehicle is unchanged.

Accepting this design as final, an analysis of it is performed to show that is meets the other design criteria.

c. General Design Requirements

The design given previously meets the general design requirements (see 3.1.1):

a. The design utilizes two steel leaves; this insures the structural integrity of the attaching member since it employs the presently used leaves

b. The supporting leaves are of fiberglass-epoxy; the weight of the spring assembly has been reduced by more than 145 pounds through this redesign

c. The composite leaves have wear pads between them and the other components of the spring assembly to protect them

d. The steel fiberglass design is interchangeable with the present steel design

e. To provide leaf alignment, a center bolt will be used. This bolt is in an area of zero bending load if the seat clamp is tight. As such, the stress concentration in the composite due to the hole is not a problem. If the seat clamp is not tight, some stress will exist in the leaves in the area of the hole. In the composite, the stress concentration factor caused by the hole is approximately 6, whereas in steel the factor is about 4 (see Advances in Joining Technology, J. Burke, A. Gorum, and A. Tarpinian, 1976, p. 405-452). Thus, the use of a center bolt is acceptable.

f. Frame height has not been altered

d. Performance Requirements for Spring Assembly

Some of the performance requirements for the spring assembly were criteria of the design process:

a. The unclamped spring rate of the assembly is 5,983 pounds/inch.

b. The spring has a design life of 150,000 cycles under the vertical load of 31,620 pounds.

c. Fiberglass-epoxy has the required impact resistance to meet life requirements.

d. The properties used for fiberglass-epoxy in the design are appropriate for the temperature range of -40°F to 160°F. These properties do not deteriorate when exposed to vehicle fluids.

e. The design has wear pads between the composite leaves to protect them from wear and excessive heat buildup due to friction. Wear pads have been used in previous designs without accumulation of foreign matter in the spring assembly.

The remaining performance requirements must be investigated.

a. The design shall be capable of withstanding a transverse load of 0.75g = 11,850 pounds. This load acts on the steel main leaf and causes a maximum shear stress of:

$$\tau = \frac{3}{2} \, \frac{(11{,}850/2)}{4 \times 0.558} = 3{,}982 \text{ psi}$$

The fatique allowable shear stress in the steel is greater than 40,000 psi.

b. The design shall be capable of sustaining 11° of longitudinal twist from the axle seat to the eye when the 31,620 pound vertical load is applied.

Consider a steel leaf of the dimensions shown in Figure 3. This beam is clamped at one end and has a 11° twist at the other. Using formulae developed in Theory of Elasticity by S. Timoshenko and J. N. Goodier, the torque T required is:

$$\frac{T}{\phi} = c_2 \, \frac{G \, a \, b3}{L}$$

where

ϕ = 11° = 0.192 radians

L = 23.50 inches

a = 4, b= 0.558, c_2 = 0.300

G = 11.54Msi

then

T = 19,660 lb-in.

The maximum shear stress resulting from this load is:

$$\tau = C_1 \, \frac{T}{ab^2}$$

where

C_1 = 3.34

or

τ = 52.725 psi

Since the present steel design has to meet this same criterion, this stress level is therefore acceptable. It is below the maximum allowable shear stress.

The composite leaves can be analyzed assuming that the load resultant of 30,544 pounds takes place at each end of the spring as shown in Figure 4.

It is shown below that, with the preload, the load to be carried by the composite leaves is 30,544 pounds.

This causes an applied torque on the leaves of:

$$T = \frac{(30,544)}{2} \quad (2)$$

$$= 30,544 \text{ inch-pounds}$$

or, per leaf

$$T = \frac{30,544}{5} = 6,109 \text{ inch-pounds}$$

This results in a maximum shear stress of:

$$\tau = c_1 \frac{T}{ab^2}$$

$$a = 4, \quad b = 0.724, \quad c_1 = 3.42$$

$$\tau = 3.42 \frac{6,109}{(4)\ (0.724)^2}$$

$$\tau = 9,965 \text{ psi}$$

The shear allowable is 12,000 psi; the margin of safety is then 20.4%.

c. The design shall be capable of withstanding and maintaining a 150,000 pound clamp load, exerted by the U-bolts, at axle seat while in service.

The plate area for the seat clamp is:

$$A = 11.5 \times 4 = 46.0 \text{ inches}^2$$

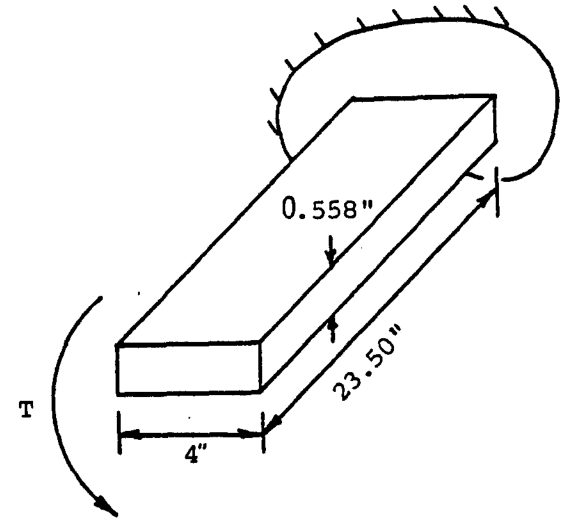


FIGURE 3 STEEL MAIN LEAF UNDER AN APPLIED TORQUE LOAD

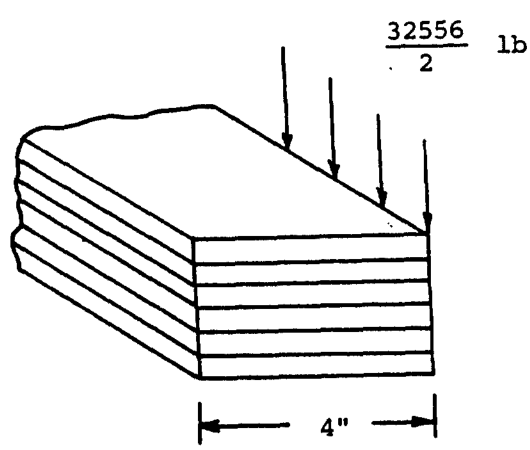


FIGURE 4 LOADING ON COMPOSITE LEAVES DUE TO AN APPLIED TORQUE

A clamping load of 150,000 pounds thus causes a compressive stress in the leaves of:

$$\sigma = \frac{150,000}{46.0} = 3,260 \text{ psi}$$

The allowable compressive stress in the composite is 16,000 psi while that in the steel is greater than 40,000 psi.

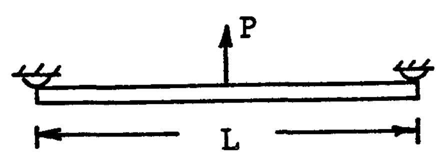
e. <u>Stresses in Steel Main Leaf in Final Design</u>

The SAE <u>Manual on Design and Appliction of Leaf Springs</u>, SAE J788a, 1970, gives formulae for symmetrical semi-elliptic leaf springs. The equation for maximum normal stress in the spring is:

$$\sigma = \frac{3LP}{2wNt^2}$$

where

L is shown in the figure below
t = thickness of leaves
N = number of leaves
w = width of leaves



Spring Geometry

For the presently used steel design:

w = 4 inches
t = 0.558 inch
N = 13
L = 54.00 inches

and, thus, the maximum normal stress under the fatique load of 31,620 pounds is:

$$\sigma = \frac{3(54)\ (31,620)}{2(4)\ (13)\ (.558)^2}$$

$$\sigma = 158,200 \text{ psi}$$

One method for analytically determining the maximum stress in the steel leaves of the hybrid design is to note the measurements of the deflections and stresses in very accurately made multileaf springs have shown that the same formulae apply as if it were a one-leaf spring of appropriate width. This is a preliminary procedure for determining the lengths of the leaves in a multileaf spring. To apply this method to the hybrid spring design, the width of the composite leaves must be adjusted to simulate the constant thickness steel leaves:

$$(EI)_{\text{composite leaf}} = (EI)\ \text{simulated leaf}$$

where

$$(EI)\ \text{simulated leaf} = E\ \text{steel}\ \frac{(1\ )\ (b)\ (t3)}{12}$$

and

t = thickness of steel main leaf
b = resulting width of simulated leaf

Using this process, the stresses in the steel leaves of the hybrid design were calculated. For the case of 0.558 inch thick steel leaves, the maximum normal stress is 198,000 psi. This is greater than in the current steel spring; it may be reduced to 158 ksi by introducing a preload. This will place an additional 1,274 pound load in the composite leaves. Analysis of the composite leaves under this load yields a maximum flexural stress (in the composite leaves) of 54 ksi. This is acceptable.

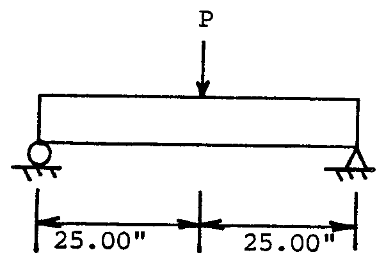
f. <u>Analysis of Front Spring Assembly</u>

The dimensions of the present steel spring are given in the TACOM drawing for P/N 7411110. For the analysis of the load distribution, the spring is taken in the flat condition. Thus, the distance from the eye to the center bolt is 25 inches.

For the three-inch wide leaves, the results are:

(1) Steel Main Leaf

The 0.447 inch thick present steel main leaf has a spring rate of 268 pounds/inch:



$$\delta = \frac{PL^3}{48EI}$$

$$E = 30 \times 10^6 \text{psi}$$

$$I = \frac{1}{12} \quad (3) \quad (.447)^3$$

where

δ = deflection under the load P

thus

P/δ = 268 pounds/inch

(2) The composite leaves, therefore, need to have a spring rate of:

K = 2,780 - 2(268) = 224 pounds/inch

The portion of the vertical load carried by the steel main leaf is:

$$\text{Load in Steel Leaf} = \frac{(268)}{2,780} \quad (11,120) = 1,072 \text{ pounds}$$

Thus, the design criteria for the composite leaves are:

Spring rate = 2,244 pounds/inch
Load = 11,120 - 2,144 = 8,976 pounds

Using these and the material properties in the composite program for leaf springs developed by EEMD gives a spring assembly of two steel leaves, each 0.447 inch thick, and two fiberglass-epoxy leaves. The composite leaves are tapered with a seat thickness of 1.60 inches per leaf and a tip thickness of 0.643 inch per leaf. Both are of the same length and span between the two end supports. The total weight of the leaves is:

48.6 pounds of steel
24.4 pounds of fiberglass-epoxy
73.0 pounds total

The result of this design is a stack height of 4.2 inches; this is 0.70 inches less than the present steel spring and will change the frame height of the vehicle. This will be increased to match present stack height by using risers in the final design.

Accepting this design as final, an analysis is performed to show that it meets the other design criteria.

g. General Design Requirements

The design given above meets the general design requirements (see Section 3.1.1):

(1) The design utilizes two steel leaves; this ensures the structural integrity of the attaching member since it employs the presently used leaves.

(2) The supporting leaves are of fiberglass-epoxy; the weight of the spring assembly has been reduced by more than 76 pounds through this redesign (neglecting riser plates)

(3) The composite leaves have wear pads between them and the other components of the spring assembly to protect them

(4) The steel-fiberglass design is interchangeable with the present steel design

(5) To provide leaf alinement, a center bolt will be used. This bolt is in an area of zero bending load if the seat clamp is tight. As such, the stress concentration in the composite due to the hole is not a problem. If the seat clamp is not tight, some stress will exist in the leaves in the area of the hole. In the composite, the stress concentration factor caused by the hole is approximately 6, whereas in steel the factor is about 4 (see Advances in Joining Technology, J. Burke, A. Gorum, and A. Tarpinian, 1976, p. 405-452). Thus, the use of a center bolt is acceptable.

(6) Frame height has been altered; risers will be added in the final design to eliminate this problem.

h. Performance Requirements for Spring Assembly

Some of the performance requirements for the spring assembly were criteria on the design process:

(1) The unclamped spring rate of the assembly is 2,780 pounds/inch.

(2) The spring has a design life of 150,000 cycles under the vertical load of 11,120 pounds.

(3) Fiberglass-epoxy has the required impact resistance to meet life requirements.

(4) The properties used for fibeglass-epoxy in the design are appropriate for the temperature range of -40°F to +160°F. These properties do not deteriorate when exposed to vehicle fluids.

(5) The design has wear pads between the composite leaves to protect them from wear and excessive heat build-up due to friction. Wear pads have been used in previous designs without accumulation of foreign matter in the spring assembly.

The remaining performance requirements must be investigated.

(1) The design shall be capable of withstanding a transverse load of 0.75g = 4,170 pounds. This load acts on the steel main leaf and causes a maximum shear stress of:

$$\tau = \frac{3}{2} \frac{(4{,}170/2)}{3 \times .447} = 2{,}332 \text{ psi}$$

The fatique allowable shear stress in the steel is greater than 40,000 psi.

(2) The design shall be capable of withstanding a longitudinal load of .8g = 4,448 pounds. This load acts on the steel main leaf and results in a normal stress of:

$$\sigma = \frac{4{,}448}{3\ (.447)} = 3{,}317 \text{ psi}$$

Fatique allowable stress in the steel is 80,000 psi.

(3) The design shall be capable of sustaining 11° of longitudinal twist from the axle seat to the eye when the 11,120 pound vertical load is applied.

Consider a steel leaf of the dimensions shown in Figure 5. The beam is clamped at one end and has a 11° twist at the other. Using formulae developed in Theory of Elasticity by S. Timoshenko and J. N. Goodier, the torque T required is:

$$\frac{T}{\phi} = c_2 \frac{G\ a\ b^3}{L}$$

where

$\phi = 11° = 0.192$ radians.
$L = 20.75$ inches
$a = 3,\ b = 0.447,\ c_2 = 0.298$
$G = 11.54$ Msi

then

$T = 8526$ inch-pounds

The maximum shear stress resulting from this loading is:

$$\tau = c_1 \frac{T}{ab^2}$$

where

$c_1 = 3.36$

or

$\tau = 47{,}790$ psi

Since the present steel design has to meet this same criterion, this stress level is therefore acceptable. It is below the maximum allowable shear stress.

The composite leaves can be conservatively analyzed assuming that the load resultan of 8,976 pounds takes place at each end of the spring as shown in Figure 6.

This causes an applied torque on the leaves of:

$$T = \frac{(8{,}976)}{2}\ (1.5)$$

$$= 6{,}732 \text{ lb-in.}$$

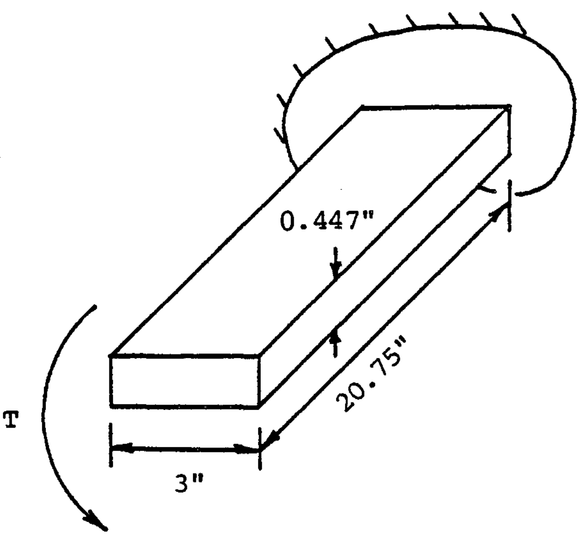


FIGURE 5 STEEL MAIN LEAF UNDER AN APPLIED TORQUE LOAD

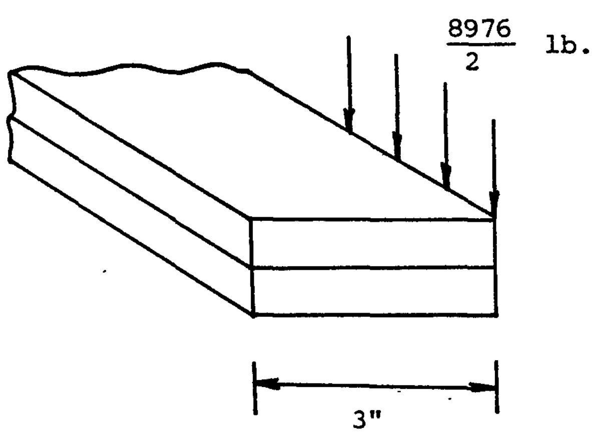


FIGURE 6 LOADING ON COMPOSITE LEAVES DUE TO AN APPLIED TORQUE

or, per leaf

$$T = \frac{6{,}732}{2} = 3{,}366 \text{ inch-pounds}$$

This results in a maximum shear stress of:

$$\tau = c_1 \frac{T}{ab^2}$$

$$a = 3, \quad b = 0.643, \quad c_1 = 3.47$$

$$\tau = 3.47 \frac{3{,}366}{(3)(.643)^2}$$

$$\tau = 9{,}417 \text{ psi}$$

The shear allowable is 12,000 psi; the margin of safety is then 21.5%.

(4) The design shall withstand acceleration and braking windup torques of 39,817 inch-pounds at the axle seat.

The reactions due to the applied torque are 796 pounds as shown in Figure 7.

Since the spring design is based on the fatique condition, this additional vertical loading has already been included in the analysis.

(5) The design shall be capable of withstanding and maintaining a 150,000 pound clamp load, exerted by the U-bolts at axle seat while in service.

The plate area for the seat clamp is:

$$A = 8.5 \times 3 = 25.5 \text{ inches}^2$$

A clamping load of 150,000 pounds thus causes a compressive stress in the leaves of:

$$\sigma = \frac{150{,}000}{25.5} = 5{,}882 \text{ psi}$$

The allowable compressive stress in the composite is 16,000 psi while that in the steel is greater than 40,000 psi.

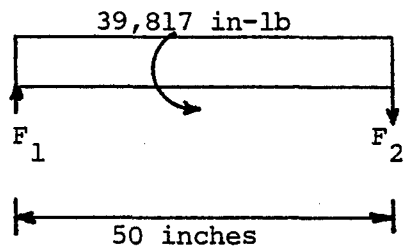


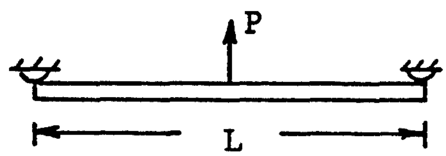
FIGURE 7 WINDUP TORQUE FORCE REACTIONS

i. Stresses in Steel Main Leaf in Final Design

The SAE Manual on Design and Application of Leaf Springs, SAE J788a, 1970, gives formulae for symmetrical semi-elliptic leaf springs. The equation for maximum normal stress in the spring is:

$$\sigma = \frac{3LP}{2wNt^2}$$

where
L is shown in the figure below
t = thickness of leaves
N = number of leaves
w = width of leaves



Spring Geometry

For the presently used steel design:

w = 3 inches
t = 0.447 inch
N = 11
L = 50.00 inches

and, thus, the maximum normal stress under the fatique load of 11,120 pounds is:

$$\sigma = \frac{3(50)(11,120)}{2(3)(11)(.447)^2} = 126,485 \text{ psi}$$

One method for analytically determining the maximum stress in the steel leaves of the hybrid design is to note that measurements of the deflections and stresses in accurately made multileaf springs have shown that the same formulae apply as if they were a one-leaf spring of appropriate width. This is a preliminary procedure for determining the lengths of the leaves in a multi-leaf spring. To apply this method to the hybrid spring design, the width of the composite leaves must be adjusted to simulate the constant thickness steel leaves:

$$(EI)_{\text{composite leaf}} = (EI)_{\text{simulated leaf}}$$

where

$$(EI)_{\text{simulated leaf}} = E_{\text{steel}} \left(\frac{1}{12}\right)(b)(t^3)$$

and

t = thickness of steel main leaf
b = resulting width of simulated leaf

Using this process, the stresses in the steel leaves of the hybrid design were calculated. For the 0.447 inch thick steel leaves, the maximum normal stress is 89,177 psi. Since this method can only yield approximate results, it is concluded that this stress is equivalent to or less than that in the present multileaf steel design. Therefore, the currently used steel leaves can be employed in the composite design.

3.1.4 Chosen Designs for Composite Assemblies

Figures 8 and 9 show the final composite designs for the rear and front leaf spring assemblies. These designs were used for the prototype fabrication program.

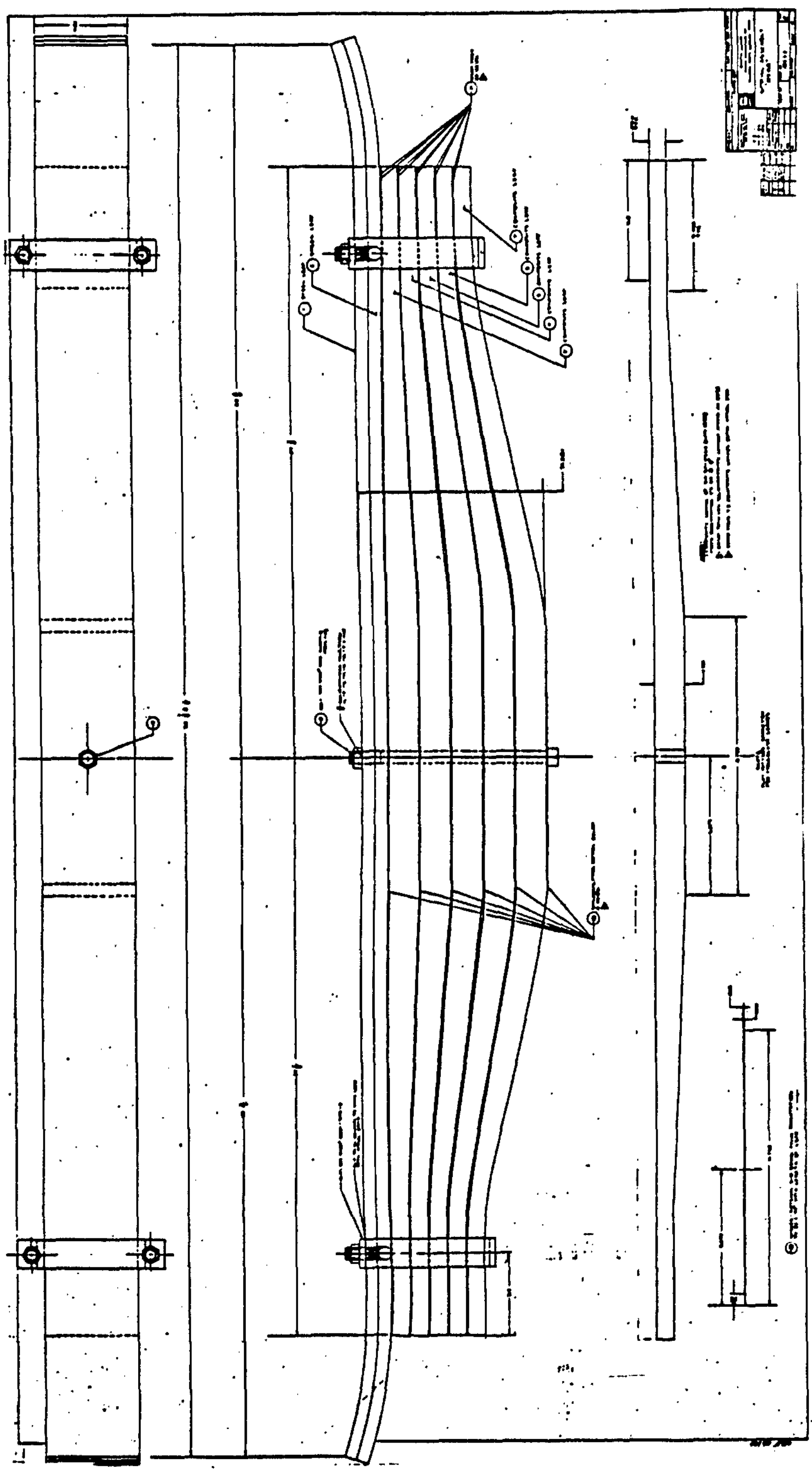


FIGURE 8(a) COMPOSITE REAR SPRING ASSEMBLY

ITEM	PART NO.	QUAN. REQD.	PART OR MATERIAL NAME
1	10032-1	1	Steel Leaf No. 1 from TACOM Assembly (7409613)
2	10032-2	1	Steel Leaf No. 2 from TACOM Assembly (7409613)
3	10032-3	1	Composite Leaf 3M SP-250-E
4	10032-4	1	Composite Leaf 3M SP-250-E
5	10032-5	1	Composite Leaf 3M SP-250-E
6	10032-6	1	Composite Leaf 3M SP-250-E
7	10032-7	1	Composite Leaf 3M SP-250-E
8	10031-13 Sheet 2	1	Bolt,1/2-20 UNF 2A See Dwg 10031 Sheet 2
9		1	Nut,1/2-20 UNF 2A Std
10		6	Spacer See Dwg 10032
11		20	Wear Pad See Dwg 10032
12	10031-14 Sheet 2	2	Clip See Dwg 10031 Sheet 2
13		AR	Hysol EA-8
14		AR	Hysol 934
15		AR	EA 3532

Figure 8 (b) COMPOSITE REAR SPRING PARTS LIST (P/N 10032)

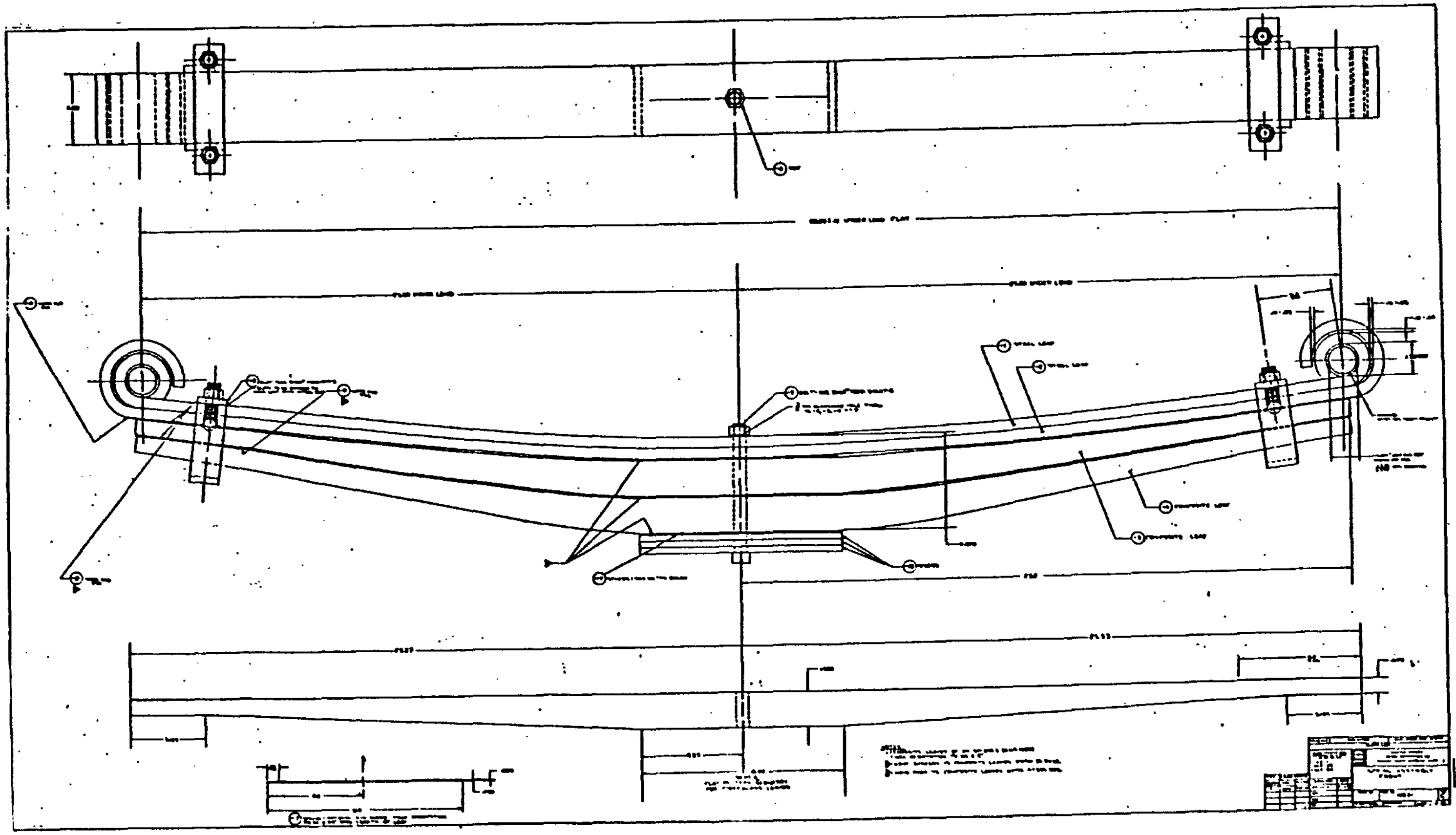


FIGURE 9 (a)   COMPOSITE FRONT SPRING ASSEMBLY

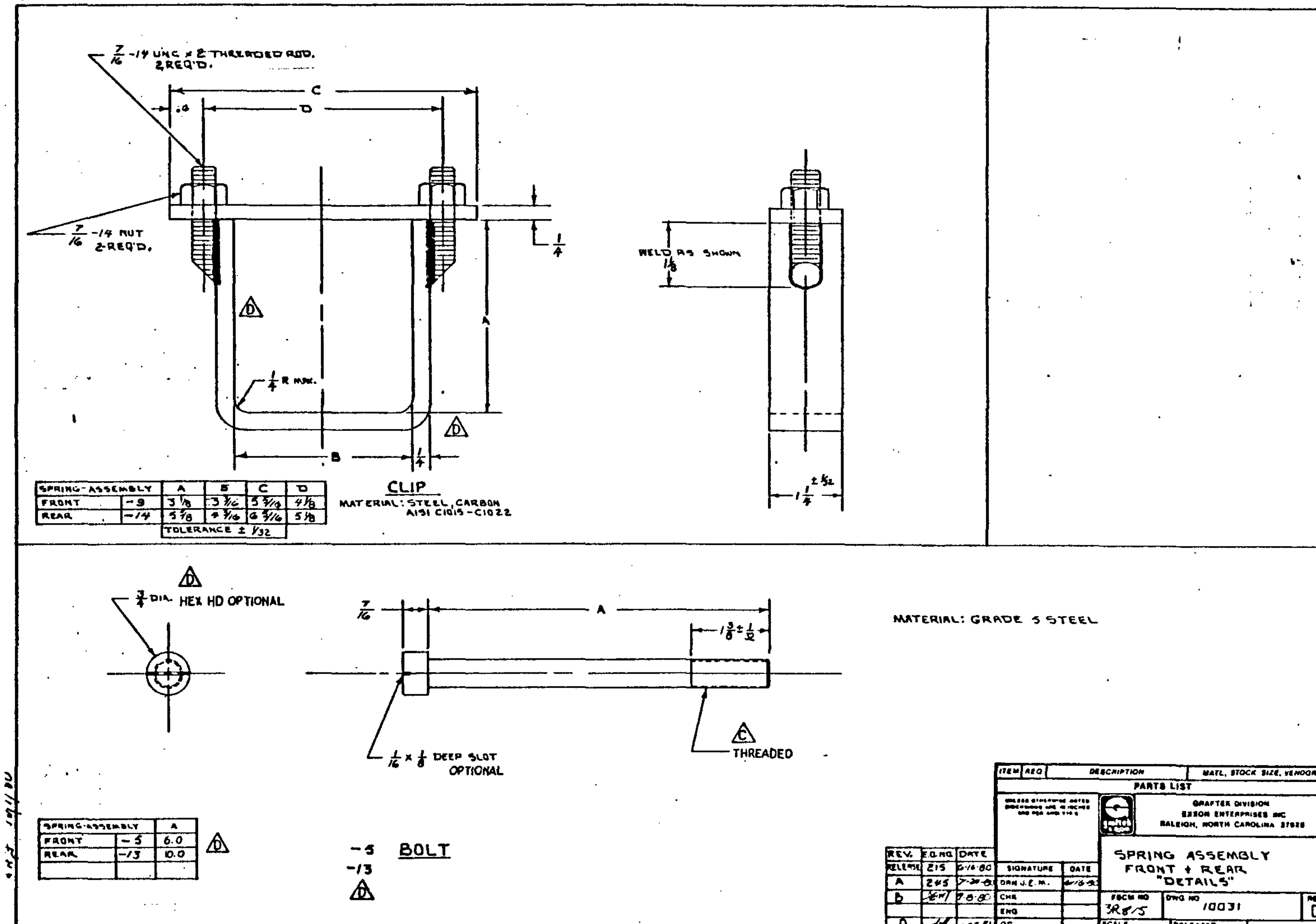


FIGURE 9 (b) COMPOSITE FRONT SPRING ASSEMBLY

ITEM	PART NO.	QUAN. REQD.	PART OR MATERIAL NAME
1	10031-1	1	Steel Leaf No. 1 from TACOM Assembly (7411111)
2	10031-2	1	Steel Leaf No. 2 from TACOM Assembly (7411112)
3	10031-3	1	Composite Leaf 3M SP-250-E
4	10031-4	1	Composite Leaf 3M SP-250-E
5	10031-5 Sheet 2	1	Bolt, 1/2-20 UNF-2A See Dwg 10031 Sheet 2
6		1	Nut, 1/2-20 UNF 2A Std
7		3	Spacer See Dwg 10031 Sheet 1
8		8	Wear Pad See Dwg 10031 Sheet 1
9	10031-9 Sheet 2	2	Clip See Dwg 10031 Sheet 2
10		AR	Hysol EA-8
11		AR	Hysol 934
12		AR	EA 3532

Figure 9 (c) COMPOSITE FRONT SPRING PARTS LIST (P/N 10031)

3.2 Propeller Shafts

Two propeller shafts for the 5-ton truck were chosen for study as part of the program to develop lightweight, experimental truck components. We studied two 5-ton trucks. The design results for all four shafts are presented in this section; however, only two of the shafts were fabricated.

The initial contract incorporated an internal pressure requirement for the shafts. This requirement resulted from a test for weld strength which is no longer used by the industry. Therefore, this requirement was deleted.

3.2.1 Design Criteria

The design studies were performed for the following four shafts:

P/N 8332248
P/N 11669147
P/N 8332245
P/N 8332246

For all designs, the structural integrity and interchangeability with existing parts were considered primary design criteria. The design philosophy accepted was to incorporate a composite material tube with end sleeves using the existing steel tube into the existing end fittings. This meets the interchangeability and structural integrity criteria including:

a. Maximum Operating Angle for the two-joint shaft shall be 3°40' at 4,500 RPM.

b. Length changes shall be allowed for by a spline yoke.

c. Excitation Limits shall be the same as for the present shaft:

   (1) Torsional excitation limit shall be taken as 400 rad/sec^2. This is controlled by the universal joints employed.

   (2) Inertia excitation limit shall be taken as 1,000 rad/sec^2. This is a function of driveshaft tube inertia.

   (3) Secondary couple excitation limit. This is a support controlled condition.

c. Environmental Conditions: Designs shall meet the performance requirements at ambient temperatures ranging from -40°F to +160°F.

a. <u>Design Criteria for P/N 8332248</u>

(1) Dimensional requirements:

(a) Outside diameter of shaft = 3.50 inches

(b) Length of shaft is 30.625 inches (centerline to centerline) while the tube section length is 11.625 inches

(c) End fittings, yoke, and joints shall be the same as for present component

Dana Yoke P/N 5-3-4581X
Dana Yoke P/N 5-28-167
Dana Shaft P/N 5-40-491

(2) Performance Requirements:

(a) Design shall withstand the following applied torques:

Continuously Applied Torque	7,680 lb-in.
Short Duration Torque	43,800 lb-in.
Torsional Strength Minimum Elastic Limit	57,270 lb-in.

(b) Maximum Operating Speed of the shaft shall be 4,500 RPM. Since this is a heavy truck application, the critical speed is taken as 4,500/0.75 or 6,000 RPM

b. <u>Design Criteria for P/N 11669147</u>

(1) Dimensional requirements:

(a) Outside diameter of shaft = 3.50 inches

(b) Length of shaft is 46.781 inches (centerline to centerline) while the tube section length is 37.50 inches

(c) End fittings, yokes, and joints shall be the same as for present component

Dana Yoke P/N 5-28-627
Dana Yoke P/N 5-4-1721
Dana Yoke P/N 5-53-141
Dana Center Bearing P/N 210084-2X

(2) Performance Requirements:

(a) Design shall withstand the following applied torques:

Continuously Applied Torque	7,680 lb-in.
Short Duration Torque	43,800 lb-in.
Torsional Strength Minimum Elastic Limit	78,000 lb-in.

(b) Maximum Operating Speed of the shaft shall be 4,500 RPM. Since this is a heavy truck application, the critical speed is taken as 4,500/0.75 or 6,000 RPM

c. Design Criteria for P/N 8332245

(1) Dimensional requirements:

(a) Outside diameter of shaft = 3.50

(b) Length of shaft is 53.625 inches (centerline to centerline) while the tube section length is 53.625 inches.

(c) End fittings, yokes, and joints shall be the same as for present component

Dana Yoke P/N 5-3-1341
Dana Yoke P/N 5-28-167
Dana Yoke P/N 5-40-491

(2) Performance Requirements:

(a) Design shall withstand the following applied torques to which the present shaft is exposed

Continuously Applied Torque	7,680 lb-in.
Short Duration Torque	43,800 lb-in.
Torsional Strength Minimum Elastic Limit	57,270 lb-in.

(b) Maximum Operating Speed of the shaft shall be 4,500 RPM. Since this is a heavy truck application, the criteria speed is taken as 4,500/0.75 or 6,000 RPM

d. <u>Design Criteria for P/N 8332246</u>

(1) Dimensional requirements:

(a) Outside diameter of shaft = 3.50

(b) Length of shaft is 46.375 inches (centerline to centerline) while the tube section length is 25.281 inches.

(c) End fittings, yokes, and joint shall be the same as for present component: P/N 204581-1 with 1710 couplings.

(2) Performance Requirements:

(a) Design shall withstand the following applied torques to which the present shaft is exposed:

Continuously Applied Torque	10,800 lb-in.
Short Duration Torque	57,600 lb-in.
Torsional Strength Minimum Elastic Limit	89,170 lb-in.

(b) Maximum Operating Speed of the shaft shall be 4,500 RPM. Since this is a heavy truck application, the critical speed is taken as 4,500/0.75 or 6,000 RPM.

3.2.2 Material Trade Study

Material trade studies were performed for P/N 0000432 and 8332248 considering the following materials for the composite tubes:

high-strength graphite-epoxy
high-modulus graphite-epoxy
E-type fiberglass-epoxy

Previous studies have shown that aramid epoxy systems are not appropriate for these applications.

Tables 8 and 9 give the results of the studies. As shown, all possible designs are similar on the basis of weight: none is more than 6% greater than the minimum. On the basis of material costs using 1980 anticipated prices:

Material System	Cost, Dollar/Pound
Fiberglass-epoxy	7.00
High-strength graphite-epoxy	34.00
High-modulus graphite-epoxy	48.00

The high-strength graphite-epoxy design is the best.

Since hybrid designs can experience failures from resin and fiber mixing, the all high-strength graphite-epoxy designs were chosen for the prototype program.

Table 8

RESULTS OF MATERIALS STUDY FOR PROPELLER SHAFT 11669147

Materials System Used For:	FINAL DESIGN								
0° plies	High-Strength GR/E	High-Strength GR/E	High-Modulus GR/E	High-Modulus GR/E	E-Glass	E-Glass	High-Strength GR/E	High-Modulus GR/E	E-Glass
±45° plies	High-Strength GR/E	High-Modulus GR/E	High-Modulus GR/E	High-Strength GR/E	High-Strength GR/E	High-Modulus GR/E	E-Glass	E-Glass	E-Glass
Tube Wall Thickness, inch	0.189	0.191	0.191	0.185	0.203	0.191	Impossible	Impossible	Impos.
Weight of Tube, pounds									
Steel Sleeves	1.87	1.87	1.87	1.87	1.87	1.87	--	--	--
Composite	3.73	3.77	3.77	3.65	4.00	3.77	--	--	--
Total	5.60	5.64	5.64	5.52	5.87	5.64	--	--	--
Comparative Weight	1.01	1.02	1.02	1.00	1.06	1.02	--	--	--
Materials Cost, Dollars									
Steel Sleeves	0.94	0.94	0.94	0.94	0.94	0.94	--	--	--
E-Glass Epoxy					1.33	0.67	--	--	--
High-Strength GR/E	126.68	2.69		110.60	129.51		--	--	--
High-Modulus GR/E		176.93	180.72	18.91		176.11	--	--	--
Total	127.62	180.56	181.66	130.45	131.78	177.72	--	--	--
Comparative Cost	1.00	1.41	1.42	1.02	1.03	1.39	--	--	--

Table 9

RESULTS OF MATERIALS STUDY FOR PROPELLER SHAFT -8332248

Materials System Used For:	FINAL DESIGN								
0° plies	High-Strength GR/E	High-Strength GR/E	High-Modulus GR/E	High-Modulus GR/E	E-Glass	E-Glass	High-Strength GR/E	High Modulus GR/E	E-Glass
±45° plies	High-Strength GR/E	High-Modulus GR/E	High-Modulus GR/E	High-Strength GR/E	High-Strength GR/E	High Modulus GR/E	E-Glass	E-Glass	E-Glass
Tube Wall Thickness, inch	0.146	0.142	0.142	0.142	0.160	0.148	Impossible	Impossible	Imposs.
Weight of Tube, pounds									
Steel Sleeves	1.87	1.87	1.87	1.87	1.87	1.87	--	--	--
Composite	0.56	0.54	0.54	0.54	0.62	0.57	--	--	--
Total	2.43	2.41	2.41	2.41	2.49	2.44	--	--	--
Comparative Weight	1.01	1.00	1.00	1.00	1.03	1.01	--	--	--
Materials Cost, Dollars									
Steel Sleeves	0.94	0.94	0.94	0.94	0.94	0.94	--	--	--
E-Glass Epoxy					0.39	0.26	--	--	--
High-Strength GR/E	18.97	1.02		15.23	19.21		--	--	--
High-Modulus GR/E		24.43	25.87	4.37		25.44	--	--	--
Total	19.91	26.39	26.81	20.54	20.54	26.64			
Comparative Cost	1.00	1.33	1.35	1.03	1.03	1.34	--	--	--

3.2.3 Analysis of Composite Tubes and Joints

Given below are stress analysis results for the final design for each shaft using a high-strength graphite-epoxy tube with steel end sleeves.

Several possibilities exist for the joint between the composite tube and the steel end sleeves, The lack of composite and adhesive property data as well as inadequate available stress analysis suggest the best design procedure for bonded composite joints is to treat each joint as an individual structure, test it, and modify it as the tests results indicate. Studies have shown that varying the adherences has little impact on the adhesive shear stress distribution. For bolted joints, the strength is dependent on many factors:

-the edge distance to bolt diameter ratio
-the side distance to bolt diameter ratio
-the laminate thickness to bolt diameter ratio
-the orientation of the reinforcing fibers.

Experimental studies, including some performed under this program, have shown that under torsional fatique loadings, bolted joints do not offer better structural integrity than bonded or bolted and bonded joints. Therefore, bonded joints were chosen for the final design.

a. Analysis for P/N 8332248

The final design is shown in Table 10.

The tube will have metal end sleeves of Dana Spicer tubing which has an outside diameter of 3.50 inches and a wall thickness of 0.095 inch. This results in shear stresses under the applied loads of:

Applied Torque, lb-in.	τ_{acting},psi	
57,270	34,000	(yield stress
43,800	26,000	of material)
7,680	4,560	

The composite tube will have an outside diameter of 3.46 inches. Under the applied torques the margins of safety are:

Applied Torque, lb-in.	τ_{acting},psi	τ_{all},psi	M.S., %
57,270	23,143	33,700	46
43,800	17,578	25,275	44
7,680	3,104	16,850	443
45,000	18,185	23,590	30

The torsional instability torque is:

$$T_{buck} = (21.74)(0.67)\ D(2,2)^{.625} \left\{ \frac{A(1,1)\ A(2,2) - A(1,2)^2}{A(2,2)} \right\}^{.375} \cdot \frac{r_{ave}^{\ 1.25}}{L^{0.5}}$$

where

A and D are material property matrixes

r_{ave} is the average radius

L = length of shaft = 30.625 inches

and for the composite tube

T_{buck} = 67,585 lb-in.

while

T_{max} = 52,270 lb-in.

or

M.S. = 18.0%

The critical speed, in RPM, of the shaft is:

$$W_c = 94.2 \sqrt{\frac{386.4\ E_x I}{\rho\ A\ L^4}}$$

where

$I = \frac{\pi}{64} (OD^4 - ID^4)$

OD = outside diamter of tube

ID = inside diameter of tube

ρ = 0.06 pounds/inch^3

$A = \frac{\pi}{4} (OD^2 - ID^2)$

For the composite tube, this gives 16,890 RPM while the required critical speed is 6,000 RPM.

The allowable material properties used in the design account for the tube being exposed to the temperatures in the range of -40°F to 160°F.

Metallic end sleeves are required for the composite tube so that the end fittings can be welded to the tube. The load transfer in the scarf joint between these metallic end sleeves and the composite tube requires a bond length as follows:

$$\left(\frac{\pi}{2}\right) (D)^2 (L) (\tau_{ALL}) = T$$

where

D = mean diameter of bond area, taken as 3.41 inches

T = applied torque

$_{ALL}$ = allowable shear stress in the adhesive, taken to be

Applied Torque lb-in.	τ_{ALL},psi
57,270	1,500
43,800	1,000
7,680	500

L = length of bond area

Thus,

$$L = \begin{cases} 2.09 \text{ inches based on ultimate torque} \\ 2.40 \text{ inches based on limit torque} \\ 0.84 \text{ inches based on fatique torque} \end{cases}$$

or

L = 2.09 inches

In addition, a 2-inch length of metallic sleeve at each end is required for the welding operation. A bond length of 2.85 inches was chosen for the final design.

Table 10

FINAL DESIGN FOR HIGH-STRENGTH GRAPHITE-EPOXY TUBE
FOR P/N 8332248

Laminate Configuration	
Thickness of ±45° plies, inch	0.120
Thickness of 90° plies, inch	0.030
Total Thickness	0.150
Static Allowable Mechanical Properties of Unidirectional Laminate Used In Design	
E_{11},Msi	18
E_{22},Msi	1.5
G_{12},Msi	0.6
ν_{12}	0.2
σ_1+,Ksi	160
σ_1-,Ksi	135
σ_2+,Ksi	6.4
σ_2-,Ksi	13.5
τ_{12},Ksi	8
Resulting Laminate Properties	
E_x,Msi	3.2
E_y,Msi	5.4
G_{xy},Msi	3.9
ν_{xy}	0.44
σ_x+,Ksi	13.8
σ_x-,Ksi	28.9
σ_y+,Ksi	41.1
σ_y-,Ksi	31.0
τ_{xy},Ksi	33.7

b. Analysis for P/N 11669147

The final design is shown in Table 11.

The tube will have metal end sleeves of Dana Spicer tubing which has an outside diameter of 3.50 inches and a wall thickness of 0.134 inch. This results in shear stresses under the applied loads of:

Applied Torque, lb-in.	τ_{acting}, psi	
78,000	33,955	(34,000 is the yield stress of the material)
43,800	19,070	
7,680	3,345	

The composite tube will have an outside diameter of 3.46 inches. Under the applied torques, the margins of safety are:

Applied Torque, lb-in.	τ_{acting}, psi	τ_{all}, psi	M.S., %
78,000	26,240	36,220	38
43,800	14,733	27,165	84
7,680	2,583	18,110	600
45,000	15,138	25,354	67

The torsional instability torque is:

$$T_{buck} = (21.75)(0.67)\ D(2,2)^{0.625}\left\{\frac{A(1,1)\ A(2,2)-A(1,2)^2}{A(2,2)}\right\}^{.375} \cdot \frac{r_{ave}^{\ 1.25}}{L^{0.5}}$$

where

A and D are material property matrixes

r_{ave} is the average radius

L = length of shaft = 46.781 inches

and, for the composite tube

T_{buck} = 98,320 lb-in.

while

T_{max} = 78,000 lb-in.

or

$$M.S. = 26.1\%$$

The critical speed in RPM, of the shaft is:

$$W_C = 94.2 \sqrt{\frac{386.4 \quad E_x \quad I}{\rho \quad A \quad L^4}}$$

where

$$I = \frac{\pi}{64} (OD^4 - ID^4)$$

OD = outside diameter of tube
ID = inside diameter of tube
ρ = 0.06 pounds/inch^3
$$A = \frac{\pi}{4} (OD^2 - ID^2)$$

For the composite tube, this gives 8,243 RPM while the required criteria speed is 6,000 RPM.

The allowable material properties used in the analysis account for the tube being exposed to temperatures in the range of -40°F to 160°F.

Metallic end sleeves are required for the composite tube so that the end fittings can be welded to the tube. The load transfer in the scarf joint between these metallic end sleeves and the composite tube requires a bond length as follows:

$$\left(\frac{\pi}{2}\right) (D)^2 (L) (\tau_{ALL}) = T$$

where
D = mean diameter of bond area, taken as 3.41 inches
T = applied torque
$_{ALL}$ = allowable shear stress in the adhesive, taken to be

Applied Torque lb-in.	τ_{ALL},psi
78,000	1500
43,800	1000
7,680	500

L = length of bond area

Thus,

L = 2.85 inches based on ultimate torque
2.40 inches based on limit torque
0.84 inches based on fatique torque

or

L = 2.85 inches

In addition, a 2-inch length of metallic sleeve at each end is required for the welding operation. A bond length of 2.85 inches was chosen for the final design.

Table 11

FINAL DESIGN FOR HIGH-STRENGTH GRAPHITE-EPOXY TUBE
FOR P/N 11669147

Laminate Configuration

Thickness of $\pm 45°$ plies, inch	0.024
Thickness of 90° plies, inch	0.162
Total Thickness	0.186

Static Allowable Mechanical Properties
of Unidirectional Laminate Used In Design

E_{11},Msi	18
E_{22},Msi	1.5
G_{12},Msi	0.6
ν_{12}	0.2
σ_{1+},Ksi	160
σ_{1-},Ksi	135
σ_{2+},Ksi	6.4
σ_{2-},Ksi	13.5
τ_{12},Ksi	8

Resulting Laminate Properties

E_x,Msi	4.2
E_y,Msi	3.0
G_{xy},Msi	4.2
ν_{xy}	0.77
σ_{x+},Ksi	31.9
σ_{x-},Ksi	23.8
σ_{y+},Ksi	12.9
σ_{y-},Ksi	25.8
τ_{xy},Ksi	36.2

c. Analysis for P/N 8332245

The final design is shown in Table 12.

The tube will have metal end sleeves of Dana Spicer tubing which has an outside diameter of 3.50 inches and a wall thickness of 0.095 inch. This results in shear stresses under the applied loads of:

Applied Torque, lb-in.	τ_{acting}, psi	
57,270	34,000	(34,000 is the yield stress of the material)
43,800	26,000	
7,680	4,560	

The composite tube will hae an outside diameter of 3.46 inches. Under the applied torques, the margins of safety are:

Applied Torque, lb-in.	τ_{acting}, psi	τ_{all}, psi	M.S., %
57,270	21,888	30,900	41
43,800	16,740	23,175	38
7,680	2,935	15,450	426
45,000	17,198	21,630	25

The torsional instability torque is:

$$T_{buck} = (21.75)(0.67)\ D(2,2)^{0.625}\left\{\frac{A(1,1)\ A(2,2)-A(1,2)^2}{A(2,2)}\right\}^{0.375} \cdot \frac{r_{ave}^{\ 1.25}}{L^{0.5}}$$

where

A and D are material property matrixes
r_{ave} is the average radius
L = length of shaft = 46.781 inches

and, for the composite tube

T_{buck} = 69,695 lb-in.

while

T_{max} = 57,270 lb-in.

or

$$\text{M.S.} = 21.7\%$$

The critical speed in RPM, of the shaft is:

$$W_c = \sqrt{\frac{386.4 \quad E_x \quad I}{\rho \quad A \quad L^4}} \qquad (94.2)$$

where

$$I = \frac{\pi}{64} (OD^4 - ID^4)$$

OD = outside diameter of tube

ID = inside diameter of tube

ρ = 0.06 pounds/inch^3

$$A = \frac{\pi}{4} (OD^2 - ID^2)$$

For the composite tube, this gives 7,925 RPM while the required criteria speed is 6,000 RPM.

The allowable material properties used in the analysis account for the tube being exposed to temperatures in the range of -40°F to 160°F.

Metallic end sleeves are required for the composite tube so that the end fittings can be welded to the tube. The load transfer in the scarf joint between these metallic end sleeves and the composite tube requires a bond length as follows:

$$\left(\frac{\pi}{2}\right) (D)^2 \, (L) \, (\tau_{ALL}) = T$$

where

D = mean diameter of bond area, taken as 3.41 inches

T = applied torque

τ_{ALL} = allowable shear stress in the adhesive, taken to be

Applied Torque lb-in.	$\tau_{ALL,psi}$
57,270	1500
43,800	1000
7,680	500

L = length of bond area

Thus,

$$L = \begin{cases} 2.23 \text{ inches based on ultimate torque} \\ 2.56 \text{ inches based on limit torque} \\ 0.90 \text{ inches based on fatique torque} \end{cases}$$

or

$$L = 2.56 \text{ inches}$$

In addition, a 2-inch length of metallic sleeve at each end is required for the welding operation. A bond length of 2.60 inches was chosen for the final design.

Table 12

FINAL DESIGN FOR HIGH-STRENGTH GRAPHITE-EPOXY TUBE
FOR P/N 8332245

Laminate Configuration

Thickness of $\pm 45°$ plies, inch	0.116
Thickness of 90° plies, inch	0.044
Total Thickness	0.160

Static Allowable Mechanical Properties
of Unidirectional Laminate Used In Design

E_{11},Msi	18
E_{22},Msi	1.5
G_{12},Msi	0.6
ν_{12}	0.2
σ_1+,Ksi	160
σ_1-,Ksi	135
σ_2+,Ksi	6.4
σ_2-,Ksi	13.5
τ_{12},Ksi	8

Resulting Laminate Properties

E_x,Msi	6.7
E_y,Msi	3.3
G_{xy},Msi	3.6
ν_{xy}	0.73
σ_x+,Ksi	51.1
σ_x-,Ksi	39.1
σ_y+,Ksi	14.2
σ_y-,Ksi	29.7
τ_{xy},Ksi	30.9

d. Analysis for P/N 8332246

The final design is shown in Table 13.

The tube will have metal end sleeves of Dana Spicer tubing which has an outside diameter of 3.50 inches and a wall thickness of 0.095 inch. This results in shear stresses under the applied loads of:

Applied Torque, lb-in.	τ_{acting}, psi	
89,170	33,985	(yield stress
57,600	21,955	of the material)
10,800	4,115	

The composite tube will have an outside diameter of 3.46 inches. Under the applied torques, the margins of safety are:

Applied Torque, lb-in.	τ_{acting}, psi	τ_{all}, psi	M.S., %
89,170	27,784	37,900	36
57,600	17,947	28,425	58
10,800	3,365	18,950	463

The torsional instability torque is:

$$T_{buck} = (21.75)(0.67)\ D(2,2)^{0.625}\left\{\frac{A(1,1)\ A(2,2) - A(1,2)^2}{A(2,2)}\right\}^{0.375} \cdot \frac{r_{ave}^{\ 1.25}}{L^{0.5}}$$

where

A and D are material property matrixes

r_{ave} is the average radius

L = length of shaft = 46.375 inches

and, for the composite tube

T_{buck} = 106,980 lb-in.

while

T_{max} = 89,170 lb-in.

or

$$M.S. = 20.0\%$$

The critical speed in RPM, of the shaft is:

$$W_c = 94.2 \sqrt{\frac{386.4}{\rho} \frac{E_x}{A} \frac{I}{L^4}}$$

where

$$I = \frac{\pi}{64} (OD^4 - ID^4)$$

OD = outside diameter of tube
ID = inside diameter of tube
ρ = 0.06 pounds/inch^3

$$A = \frac{\pi}{4} (OD^2 - ID^2)$$

For the composite tube, this gives 7,550 RPM while the required criteria speed is 6,000 RPM.

The allowable material properties used in the analysis account for the tube being exposed to temperatures in the range of -40°F to 160°F.

Metallic end sleeves are required for the composite tube so that the end fittings can be welded to the tube. The load transfer in the scarf joint between these metallic end sleeves and the composite tube requires a bond length as follows:

$$\left(\frac{\pi}{2}\right) (D)^2 (L) (\tau_{ALL}) = T$$

where

D = mean diameter of bond area, taken as 3.26 inches
T = applied torque
τ_{ALL} = allowable shear stress in the adhesive, taken to be

Applied Torque lb-in.	τ_{ALL},psi
89,170	1500
57,600	1000
10,800	500

L = length of bond area

Thus,

$$L = \begin{cases} 3.57 \text{ inches based on ultimate torque} \\ 3.46 \text{ inches based on limit torque} \\ 1.30 \text{ inches based on fatique torque} \end{cases}$$

or

L = 3.60 inches

In addition, a 2-inch length of metallic sleeve at each end is required for the welding operation.

A weight savings comparison of these designs to the existing tubes is shown in Table 14. Because of the required steel end sleeves, weight savings are as low as 26%.

3.2.4 Chosen Designs for Composite Shafts

The final designs are given in Figures 10 - 13:

Figure 10: Composite Design for P/N 8332248
Figure 11: Composite Design for P/N 11669147
Figure 12: Composite Design for P/N 8332245
Figure 13: Composite Design for P/N 8332246

Tolerances for all designs were chosen to agree with those for the existing steel tube used to facilitate balancing of the shaft. These tolerances are:

a. Ovality T.I.R. maximum of 0.007 inch; this is the most significant parameter for balancing

b. Straightness T.I.R. maximum runout of 0.012 inch

c. Wall thickness of ± 0.005 inch; this is greater than the ± 0.003 inch required for the steel tube, but is not the major parameter in balancing the shaft.

Table 13

FINAL DESIGN FOR HIGH-STRENGTH GRAPHITE-EPOXY TUBE
FOR P/N 8332246

Laminate Configuration

Thickness of $\pm 45°$ plies, inch	0.016
Thickness of 90° plies, inch	0.188
Total Thickness	0.204

Static Allowable Mechanical Properties
of Unidirectional Laminate Used In Design

E_{11},Msi	18
E_{22},Msi	1.5
G_{12},Msi	0.6
ν_{12}	0.2
$\sigma_{1}+$,Ksi	160
$\sigma_{1}-$,Ksi	135
$\sigma_{2}+$,Ksi	6.4
$\sigma_{2}-$,Ksi	13.5
τ_{12},Ksi	8

Resulting Laminate Properties

E_x,Msi	3.5
E_y,Msi	2.8
G_{xy},Msi	4.4
ν_{xy}	0.77
σ_x+,Ksi	26.0
σ_x-,Ksi	19.3
σ_y+,Ksi	11.9
σ_y-,Ksi	22.8
τ_{xy},Ksi	37.9

Table 14

WEIGHT COMPARISON FOR TACOM PROPELLER SHAFT TUBE SECTIONS

Part Number for Shaft	8332248	11669147	8332245	8332246
Length of Tube Section, inches	11.625	37.50	34.625	25.281
Metal Tube				
Outside Diameter, inches	3.50	3.50	3.50	3.50
Wall Thickness, inches	0.095	0.134	0.095	0.156
Weight, pounds	3.34	15.04	9.96	11.73
Composite Tube with Metal Sleeves				
Sleeves				
Outside Diameter, inches	3.50	3.50	3.50	3.50
Wall Thickness, inches	0.095	0.134	0.095	0.156
Weight, pounds	1.97	2.75	1.90	3.53
Composite				
Outside Diameter, inches	3.46	3.46	3.46	3.46
Wall Thickness, inches	0.150	0.186	0.160	0.204
Weight, pounds	0.50	3.57	2.84	2.26
Total Weight, pounds	2.47	6.32	4.74	5.79
Weight Saved by Using Composites				
Pounds	0.87	8.72	5.22	5.94
Percent	26%	58%	52%	51%

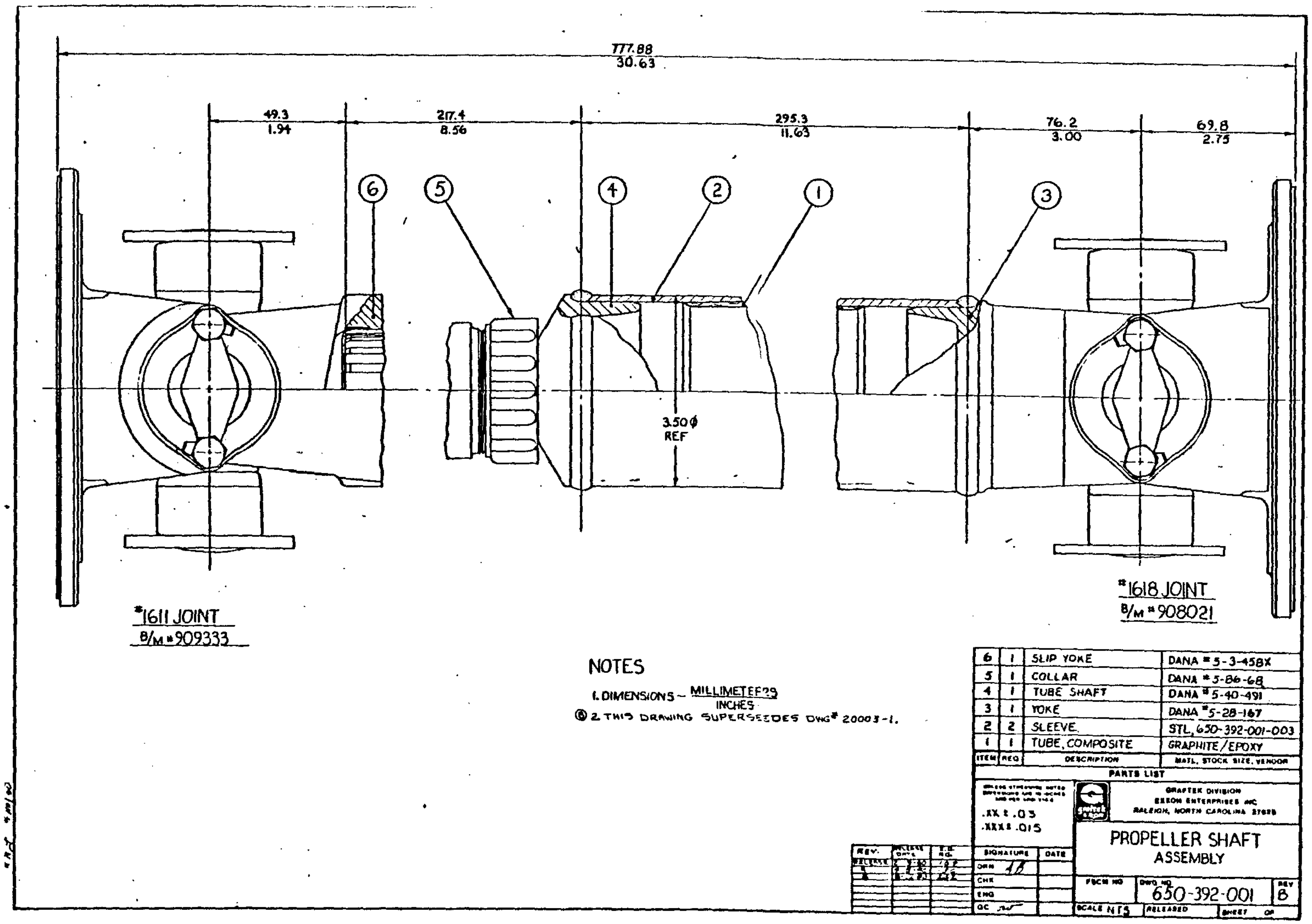


FIGURE 10(a) COMPOSITE DESIGN FOR P/N 8332248

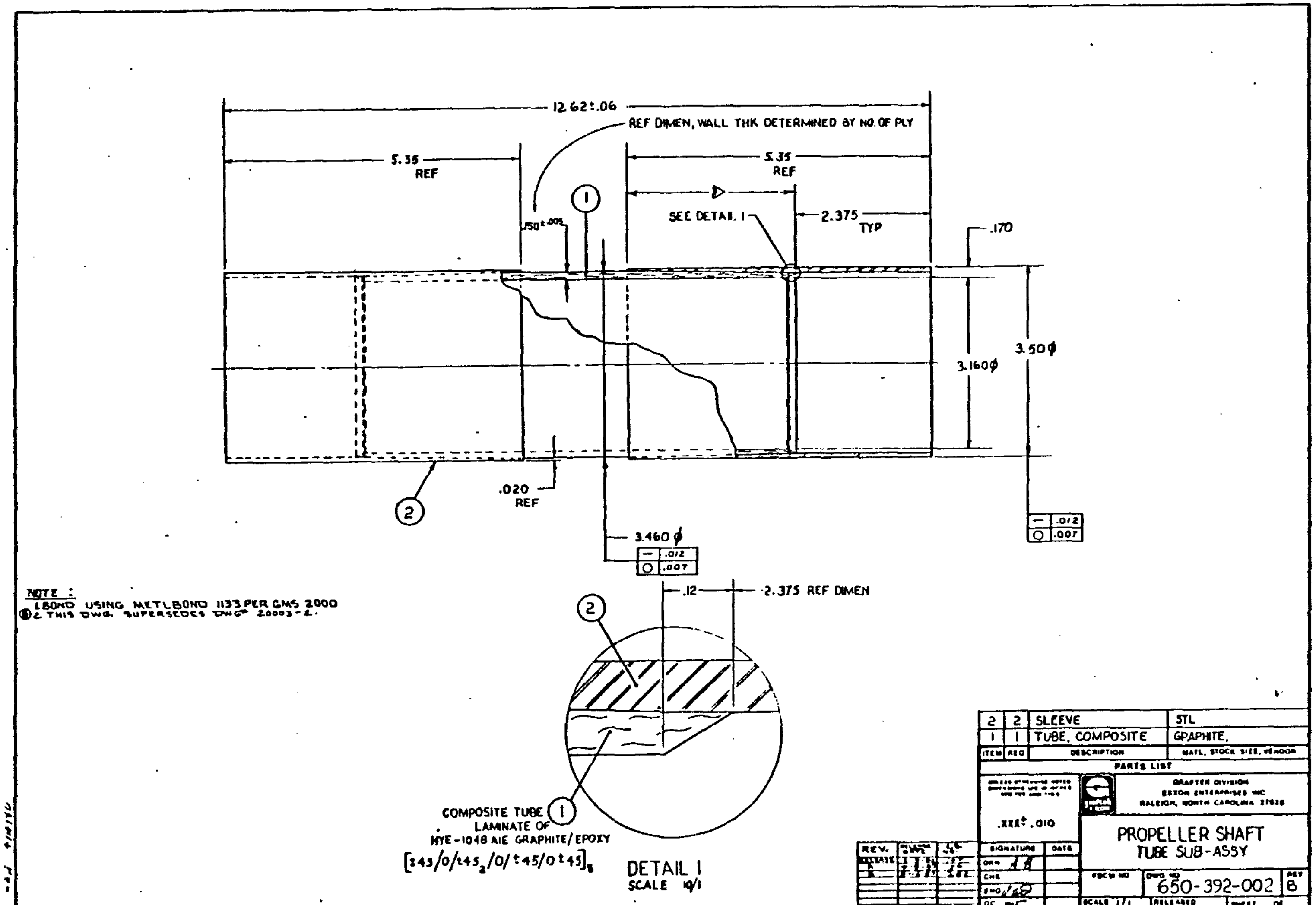


FIGURE 10(b) COMPOSITE DESIGN FOR P/N 8332248

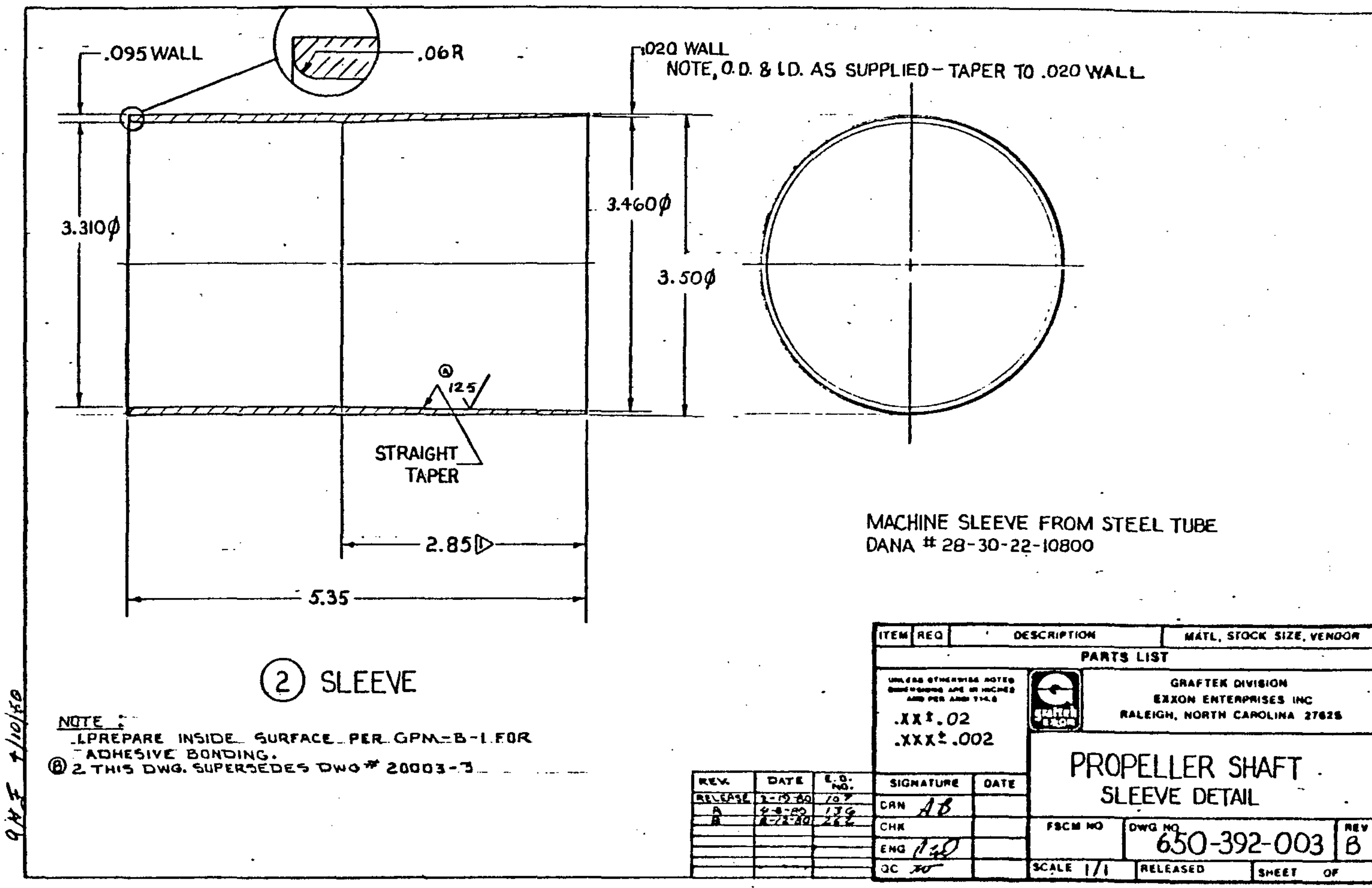


FIGURE 10(c) COMPOSITE DESIGN FOR P/N 8332248

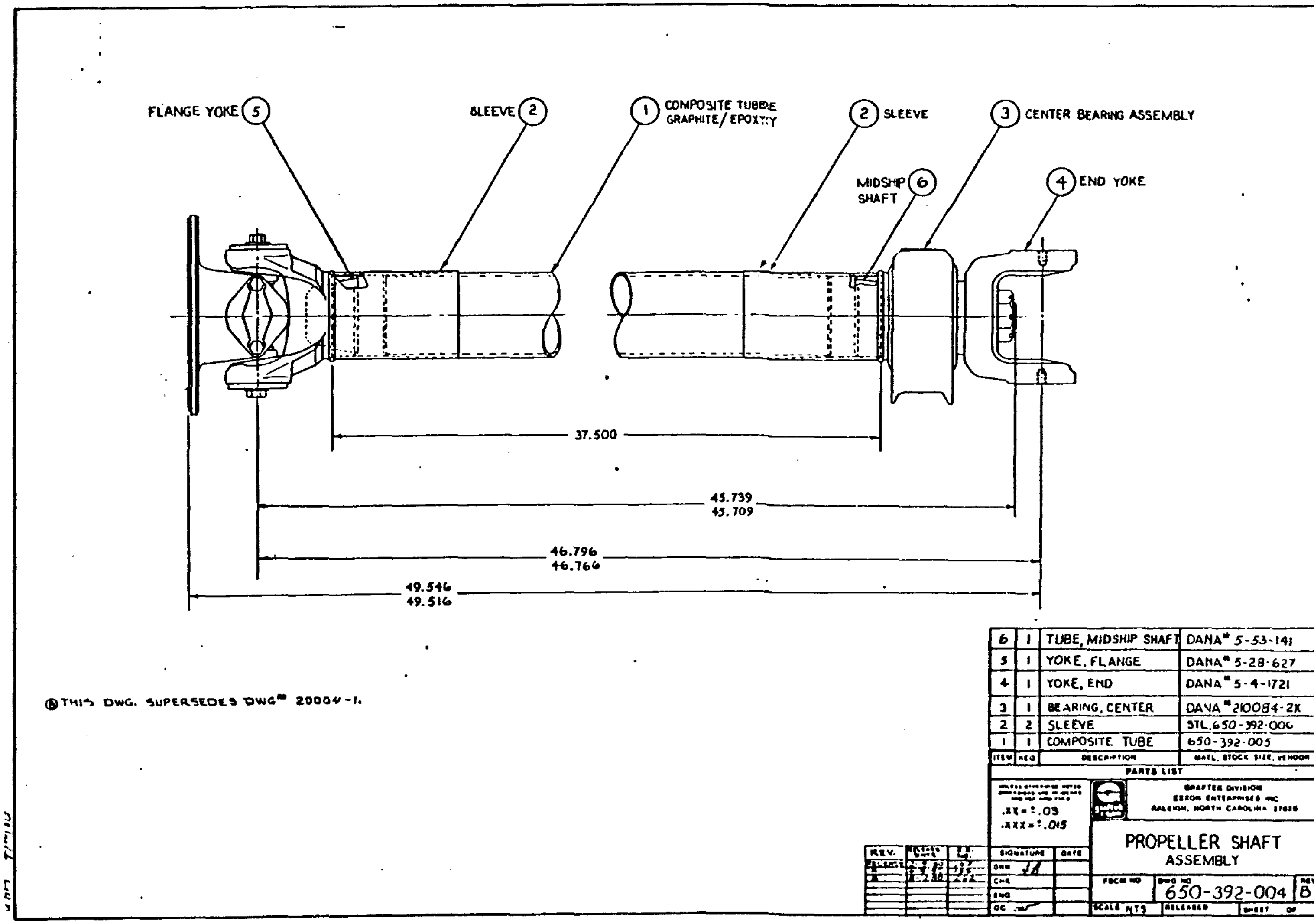


FIGURE 11 (a) COMPOSITE DESIGN FOR P/N 11669147

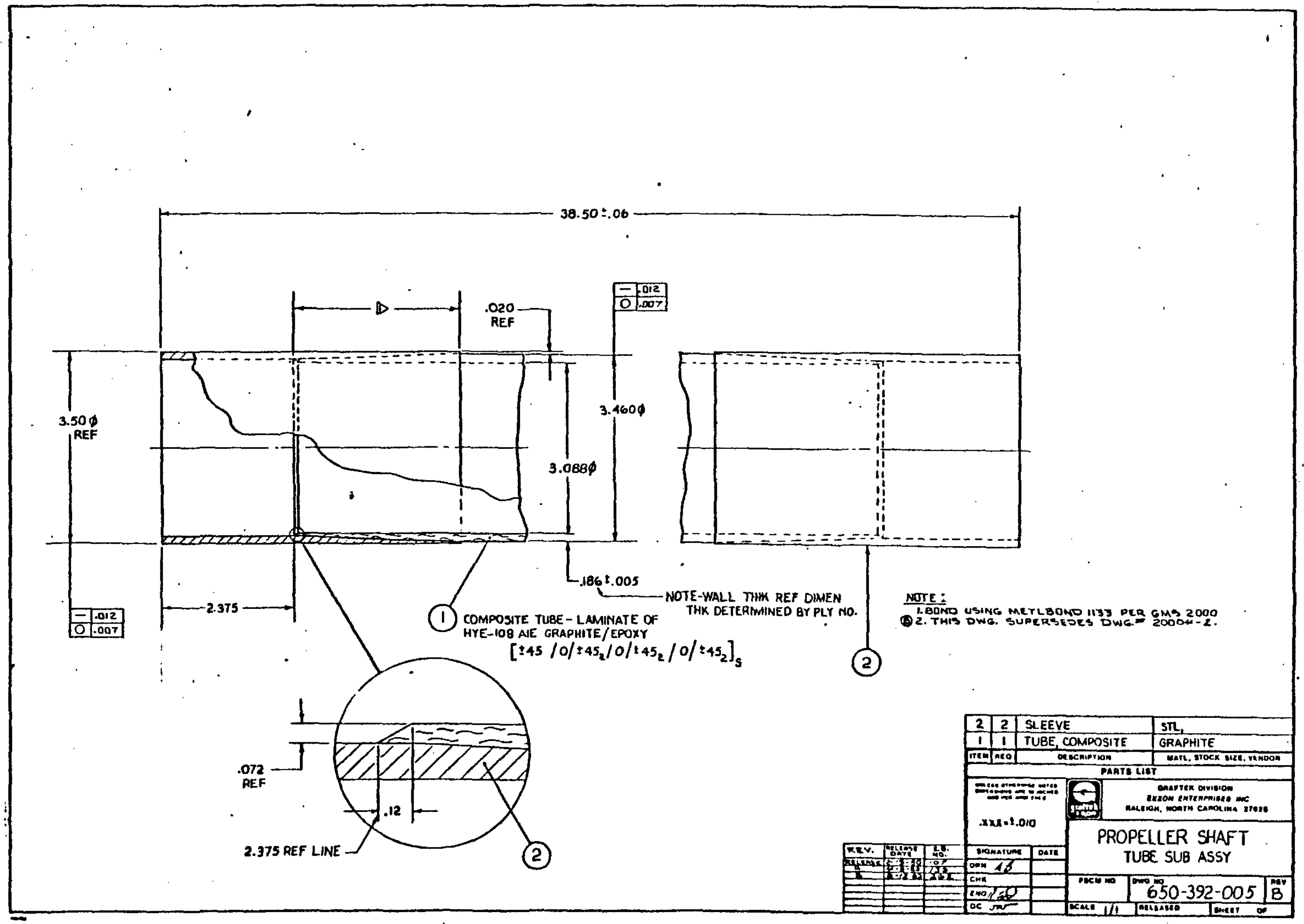


FIGURE 11 (b) COMPOSITE DESIGN FOR P/N 11669147

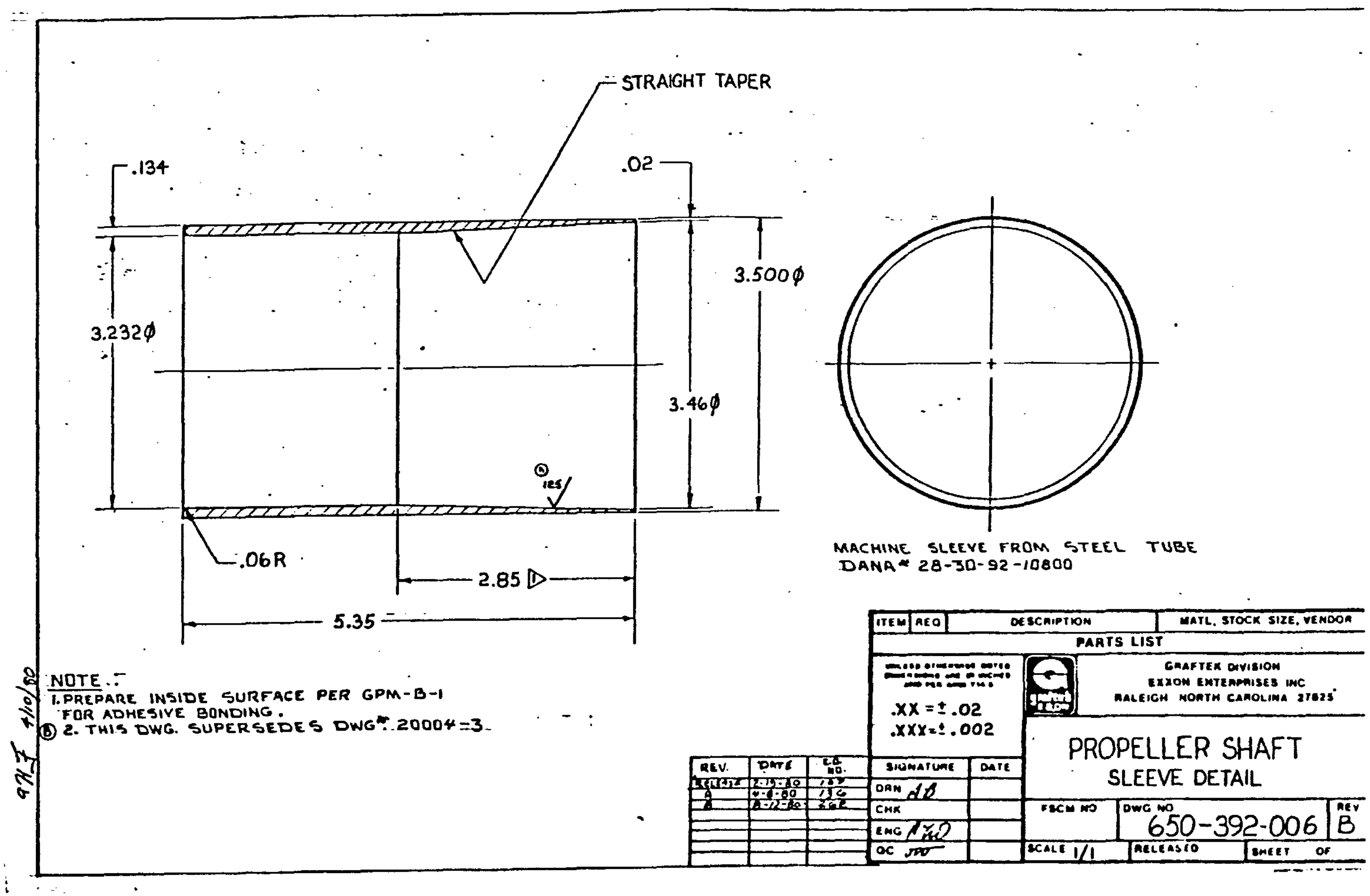


FIGURE 11 (c) COMPOSITE DESIGN FOR P/N 11669147

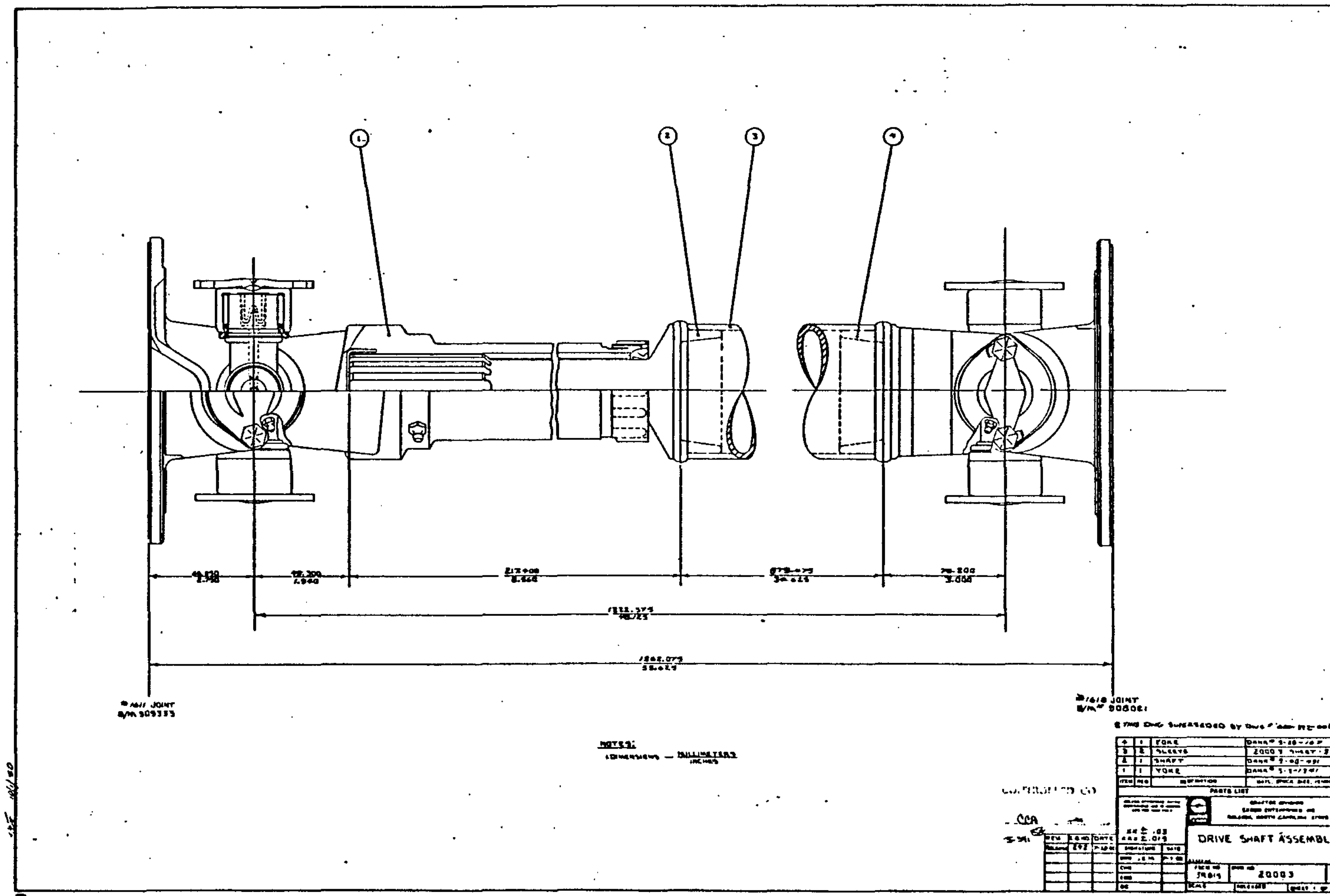


FIGURE 12 (a) COMPOSITE DESIGN FOR P/N 8332245

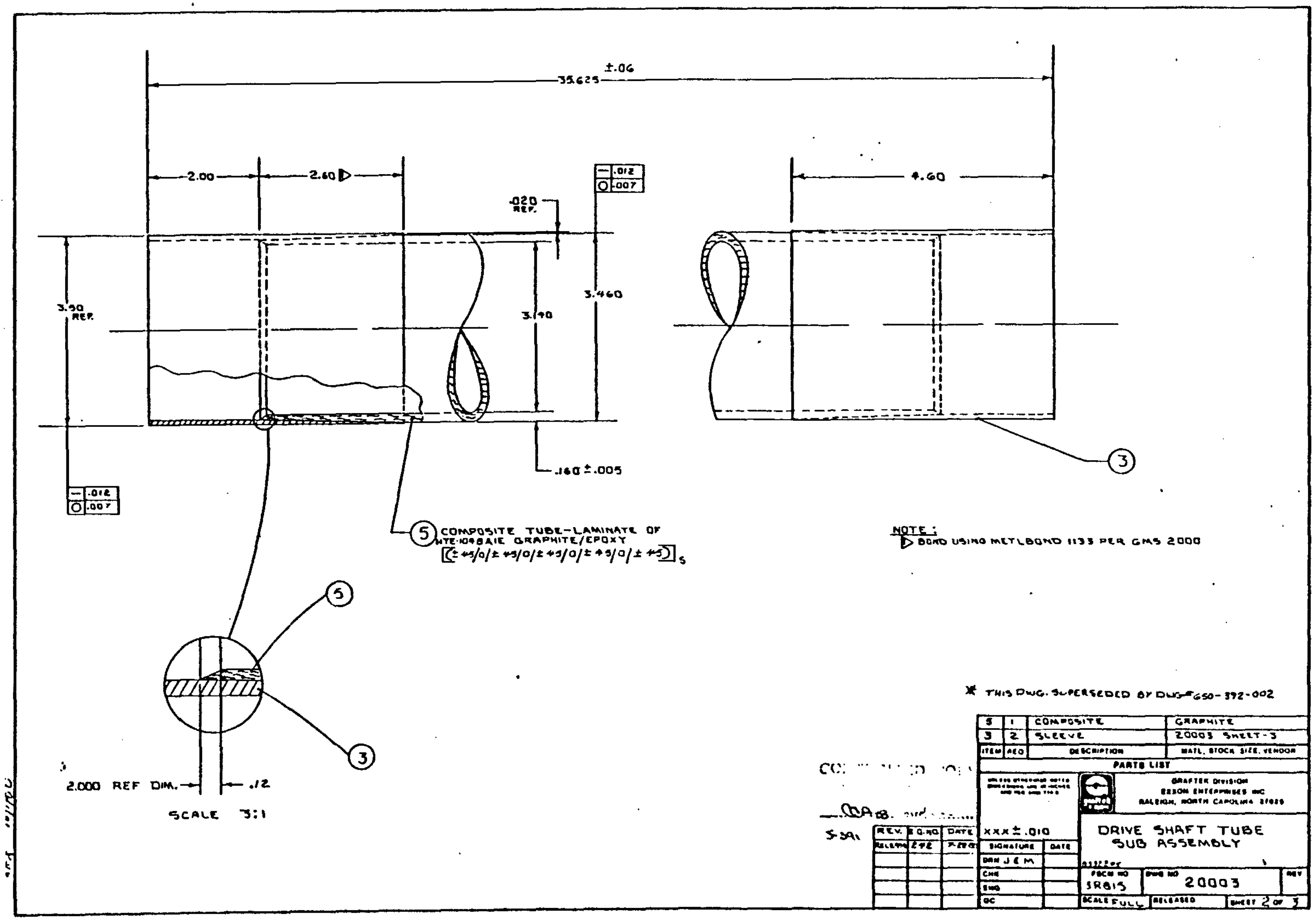


FIGURE 12 (b) COMPOSITE DESIGN FOR P/N 8332245

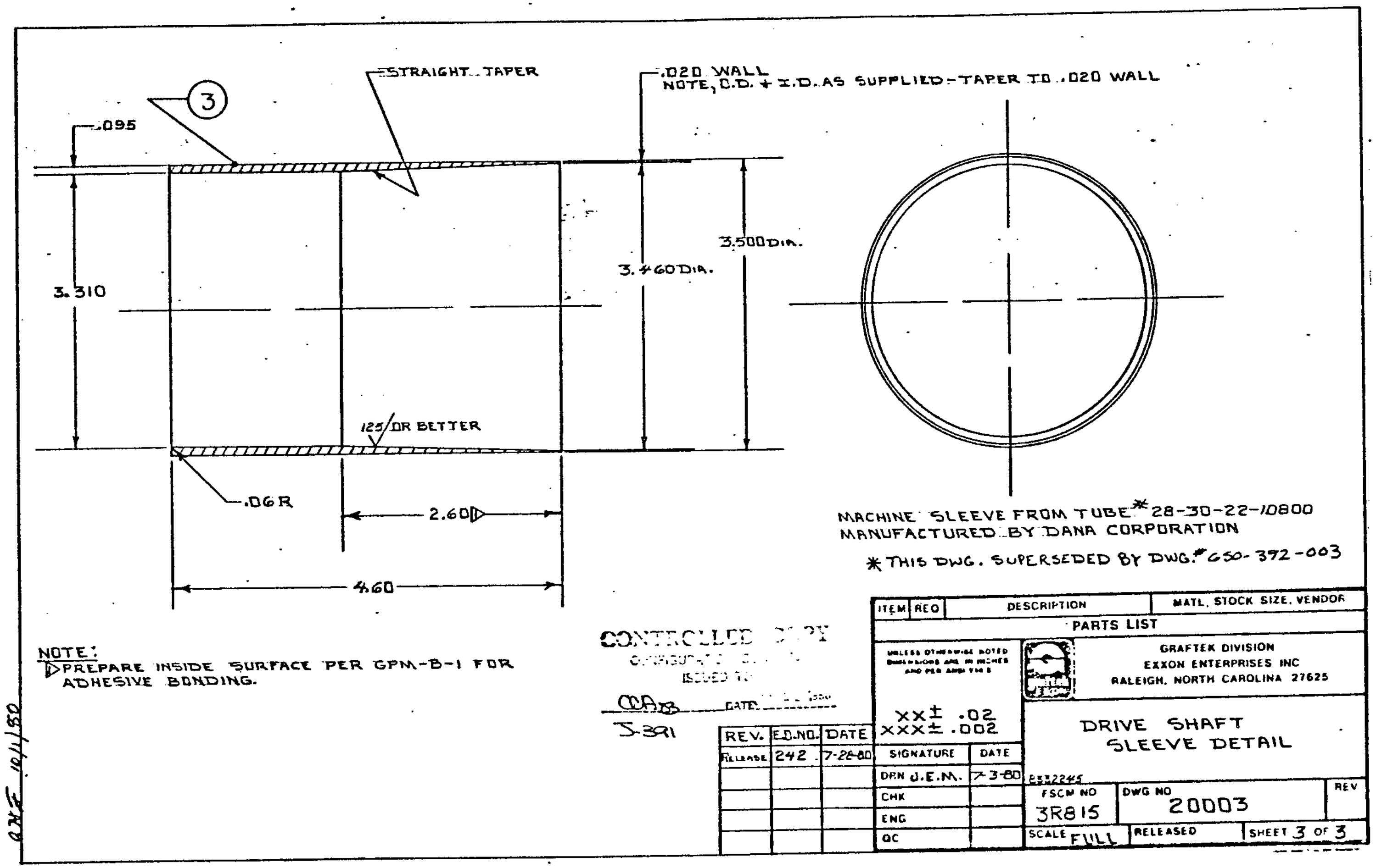


FIGURE 12 (c) COMPOSITE DESIGN FOR P/N 8332245

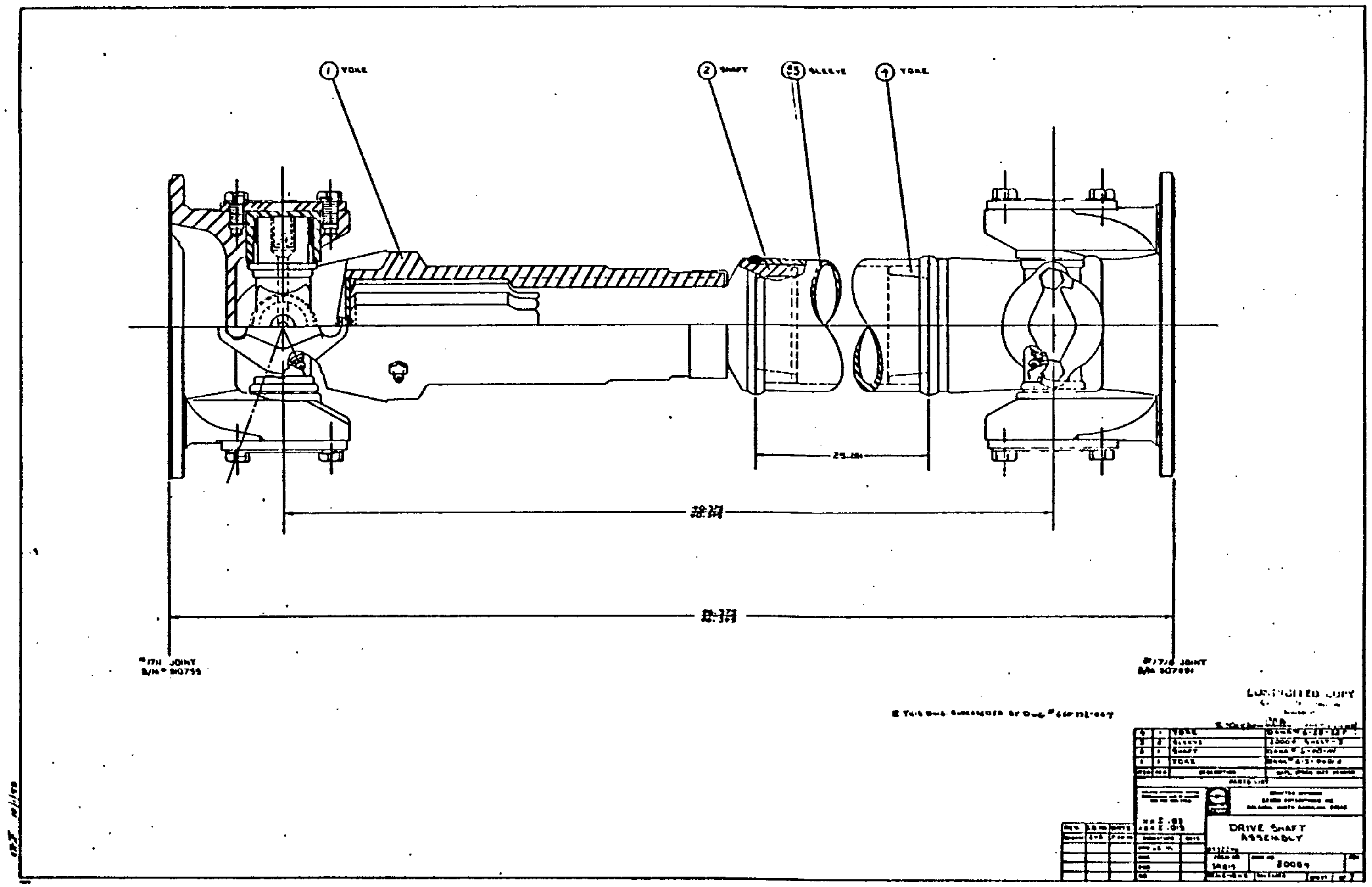


FIGURE 13 (a) COMPOSITE DESIGN FOR P/N 8332246

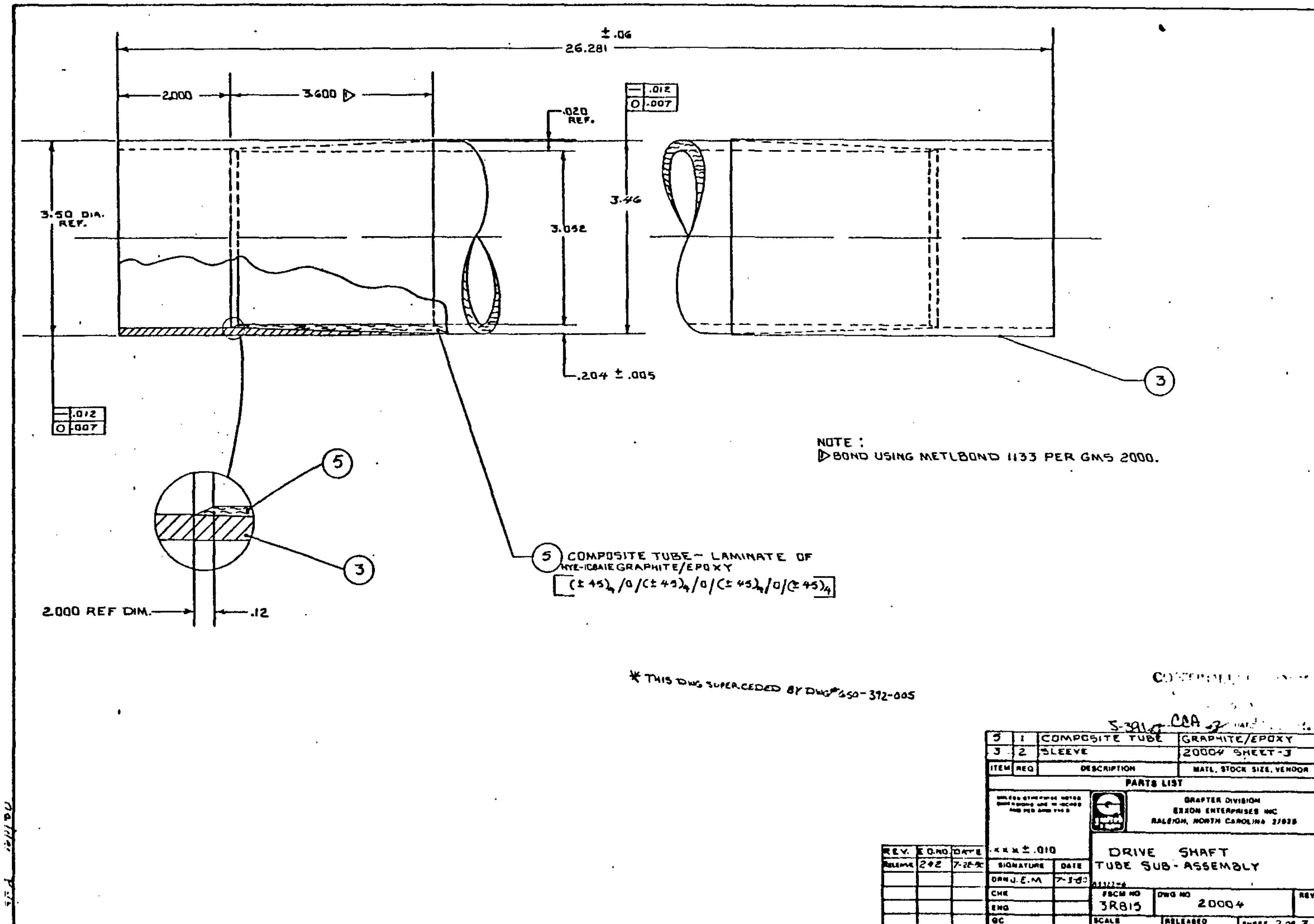


FIGURE 13 (b) COMPOSITE DESIGN FOR P/N 8332246

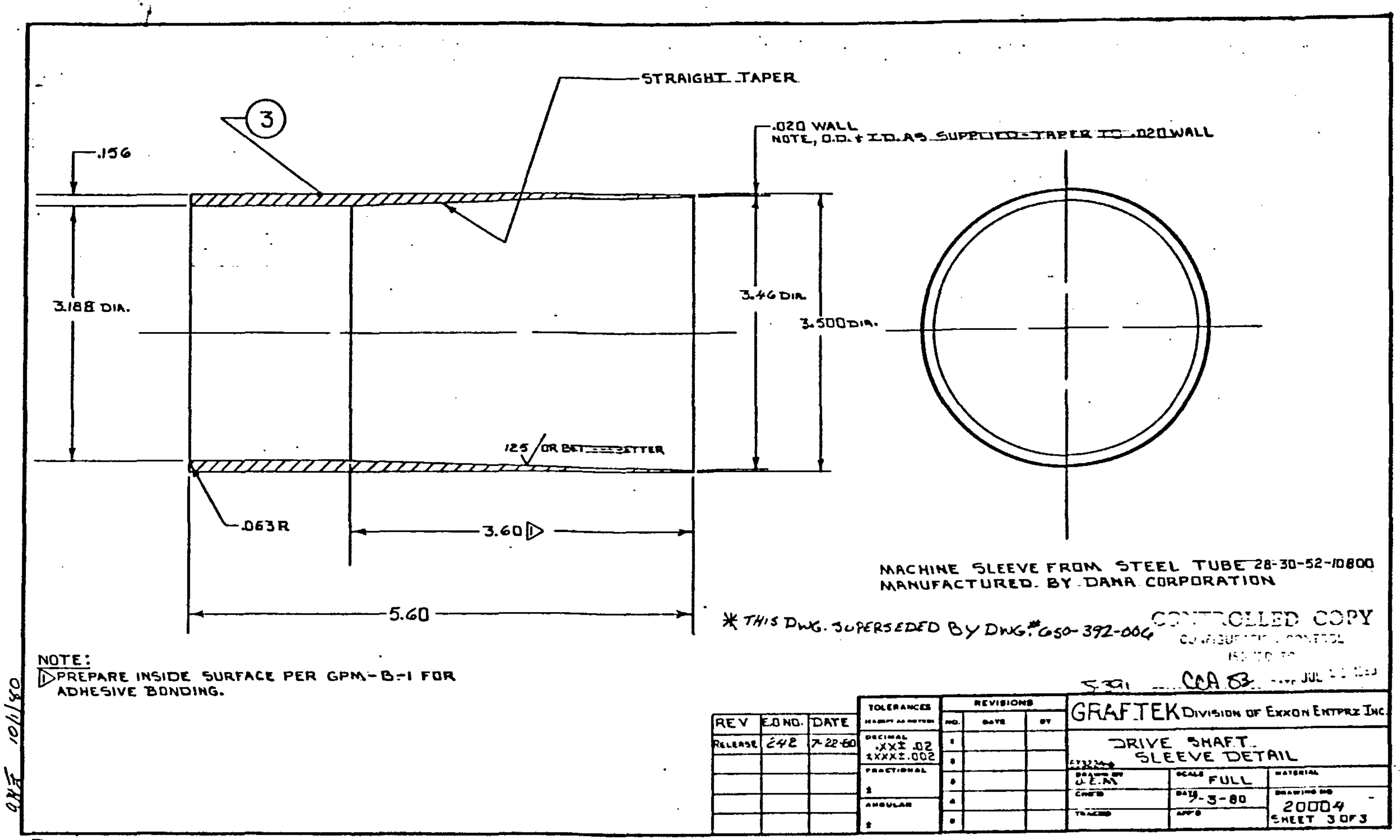


FIGURE 13 (c) COMPOSITE DESIGN FOR P/N 8332246

4

FABRICATION OF PROTOTYPE COMPONENTS

4.1 Leaf Spring Assemblies

4.1.1 Leaf Fabrication

Individual leaves of fiberglass-epoxy were fabricated from billets on expendable tooling. An example of the tooling is shown in Figure 14. The process involves laying individual prepreg plies of fiberglass-epoxy, cut to lengths to form a billet of the desired final shapes for the leaf, on the tooling. During lay-up, the material is compacted to minimize wrinkling of the material during cure. After all plies are laid-up, a caul sheet is placed on top. The billet is then cured at 85 psi and 250°F. Finally, the cured billet is cut into leaves of the desired width. Appendix A gives the step-by-step procedure for the composite leaves of the rear assembly; the process for the front assembly is similar.

4.1.2 Assembly

After the composite leaves are fabricated, spacer and wear pads are adhesively bonded to each leaf and the center bolt hole is drilled.

The assembly consists of the steel leaves, composite leaves, spacer and wear pads, risers (if required), center bolt, and clips. The final assembly is in accordance with the designs shown in Figures 8 and 9. The assembly process is given in detail in Appendix A for the front assembly, which is the more complex of the two assemblies. The proposed clip design is for prototype samples only. In production, the clip would be attached to the steel main leaf by a rivet. The prototype clip was chosen to avoid the heat treat and shot preening operations required after riveting. If these operations are not performed, the mechanical properties of the steel leaves will be inadequate for service conditions.

It should be noted that the purpose of the clip is to aline the leaves and to facilitate handling of the assembly. Thus, if the adhesive bond of the prototype design fails during service (which is expected), it does not affect performance.

Component spring assembly weights are shown in Table 15.

4.2 Propeller Shafts

4.2.1 Composite Tube Fabrication

The graphite-epoxy tubes for the propeller shaft are fabricated on a steel mandrel overwrapped with a silicone rubber bag; a typical mandrel is shown in Figure 15. The composite prepreg plies, cut in accordance with the required

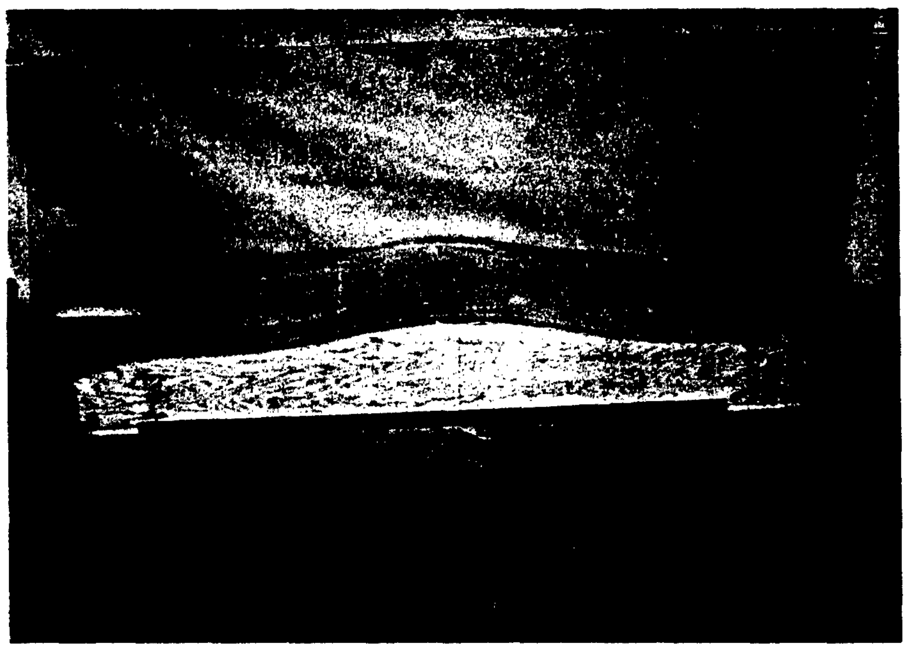
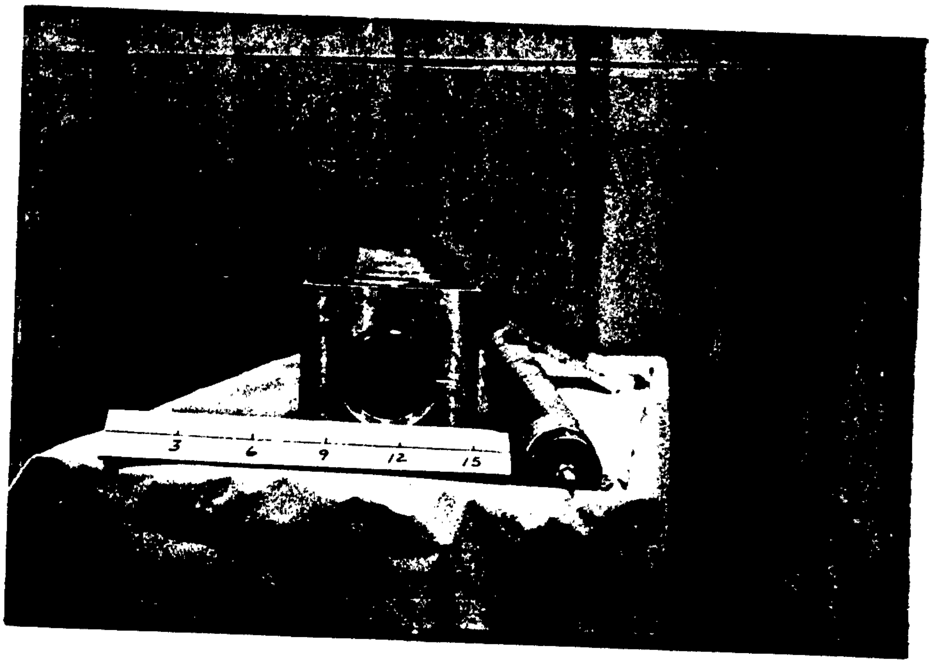


FIGURE 14

EXPENDABLE TOOLING FOR
LEAF SPRING FABRICATION

Table 15
WEIGHT OF COMPOSITE SPRING ASSEMBLIES

Component	Weight, Pounds Front Assembly	Rear Assembly
Composite Assembly:		
Steel Leaves and Clamp Bars	46.5	74.1
Composite Leaves	23.4	70.7
Brackets	2.0	3.0
Center Bolt	0.3	0.5
Risers	5.5	---
TOTAL	77.7	148.3
Steel Assembly	149.0	293.4
Weight Savings for Composite Assembly		
Pounds	71.3	145.1
Percent	48	49



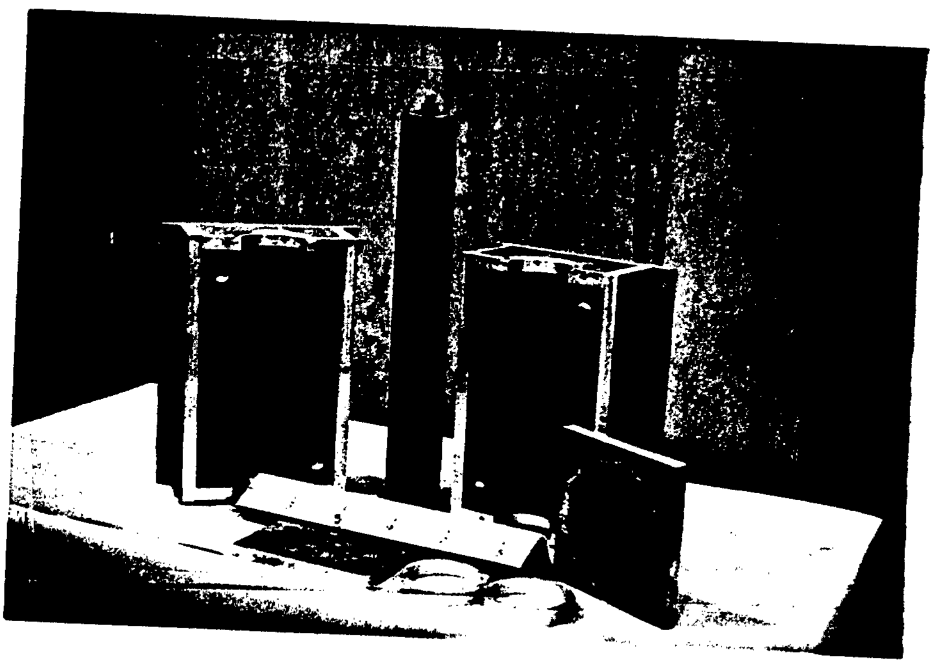


FIGURE 15

TOOLING FOR PROPELLER SHAFT
COMPOSITE TUBE FABRICATION

patterns, are then laid on the mandrel. The steel end sleeves are placed on the mandrel before it is inserted into the mold cavity, shown in Figure 15. The tube is cured at 250°F with a pressure of 85 psi applied at the inner radius of the tube. This pressure forces the composite material to expand to the mold cavity. This expansion insures a good bond between the composite tube and the end sleeves, minimizes material wrinkling, and produces a tube of the required outside diameter. This process is given in detail in Appendix B.

4.2.2 Assembly

The cured composite tube, with steel end sleeves, is designed to replace the existing steel tube of the propeller shafts. The end fittings are welded to the end sleeves. This assembly process was subcontracted to the Dana Corporation, the supplier of the existing shafts. The end fittings and welding and balancing processes employed to fabricate the existing shafts were followed. This procedure maximized the structural integrity of the composite redesign effort.

5

TEST PROGRAM

The composite components fabricated in the program were subjected to non-destructive and destructive tests.

5.1 Non-Destructive Evaluation

All composite parts fabricated were ultrasonically C-scanned to verify the fabrication process, investigate internal flaws in the material, and provide a quality assurance standard. The results of the C-scans for the prototype components are given in Appendix C.

5.2 Leaf Spring Assemblies

All leaf spring assemblies were tested statically to determine the spring rate at the rated load. Figure 16 shows the test set-up. Several of the assemblies were also tested under fatigue conditions to determine the fatigue lives of both the existing steel assembly and the composite designs. The tests were in accordance with the procedures outlined in Appendix D.

For the front assemblies, the steel and composite designs results are given in Tables 16-19 and Figures 17-19. As shown, the assemblies survived 150,000 cycles without any apparent failures. The spring rate does change with cycling, as has been shown in previous studies.

The results for the rear assemblies are given in Tables 20-24 and Figures 20 and 21. The static results are as predicted. The fatigue results for the steel assembly show that it survived 150,000 cycles without any apparent failures. The composite assemblies experienced major problems during fatigue testing. After several failures, see Tables 23 and 24, the problem was determined to be load transfer between leaves. This was caused by the nonmatching curvatures of the composite leaves in the spacer pad area. Such a problem results from the fabrication process used for the prototype parts. A production process would not exhibit this characteristic. Therefore, the test results given in Table 22 are considered indicative of the composite design: a fatique life of greater than 100,000 cycles. It is concluded that the composite design does exhibit a fatigue life common for heavy truck leaf springs and that the design is acceptable.

5.3 Propeller Shafts

Destructive testing of the fabricated propeller shafts consisted of a static test to failure and a fatigue test. The static torque test was a continuously increasing load test. The fatigue test was a continuously applied torque of $\pm$45,000 lb-in. at laboratory ambient temperature.

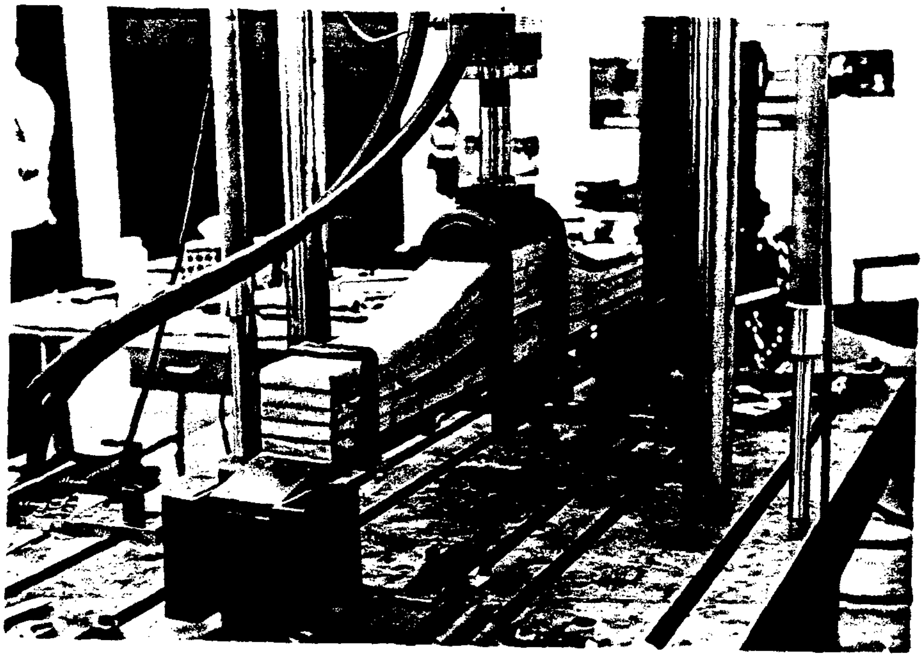


FIGURE 16(a) SPRING ASSEMBLY TEST SET-UP
REAR ASSEMBLY

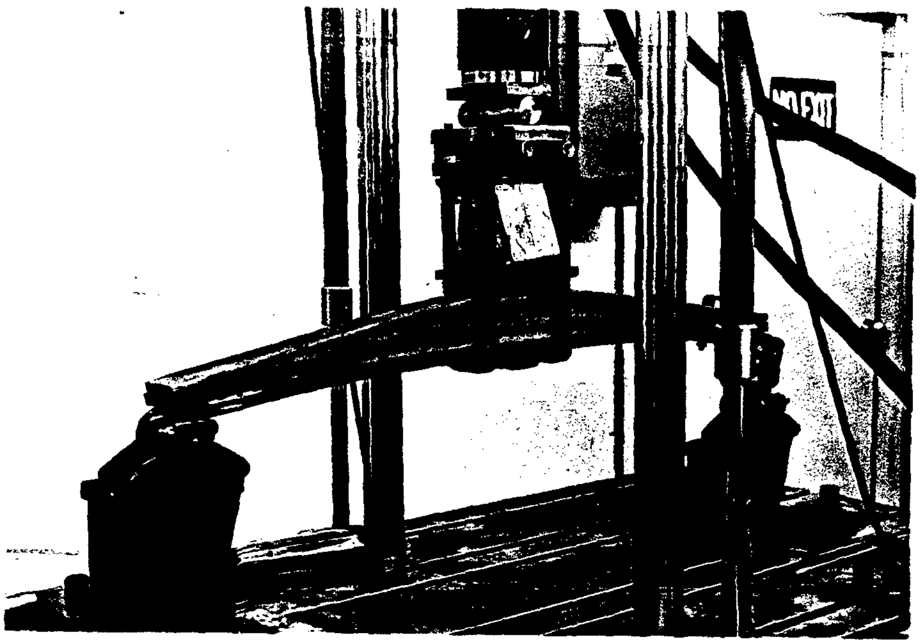


FIGURE 16(b) SPRING ASSEMBLY TEST SET-UP
FRONT ASSEMBLY

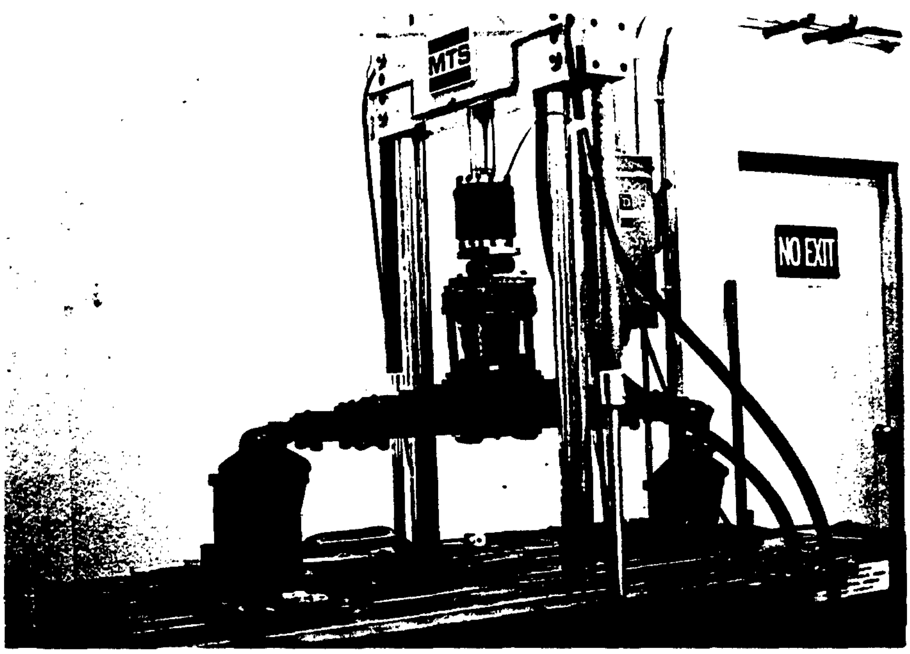


FIGURE 16(c) SPRING ASSEMBLY TEST SET-UP
FRONT ASSEMBLY

Table 16

SUMMARY OF INITIAL SPRING RATES
FOR FRONT SPRING ASSEMBLIES*

Material	S/N	Clamped Spring Rate, lb/in. at Rated Load		
		Loading	Unloading	Average
Steel	---	2,625	2,669	2,647
Composite	1	3,500	3,303	3,402
	2	3,172	3,019	3,095
	3	3,478	3,391	3,435
	4	3,172	3,041	3,107
	5	3,347	3,281	3,314
	6	3,347	3,259	3,303
	Average	3,336	3,216	3,276

*Composite Assembly Design Spring Rate was not that of the Steel Assembly

Table 17

VERTICAL FATIGUE TEST RESULTS
FOR FRONT STEEL ASSEMBLY

Cycles	Clamped Spring Rate, lb/in. at Rated Load	Torque on U-Bolts lb-in.			
1	2,625*	260	260	260	260
10,000	3,172	180	180	150	150
35,000	3,347	200	200	230	220
60,000	3,412	220	250	180	160
85,000	3,894	250	260	250	260
110,000	3,894	245	250	255	260
135,000	3,937	250	255	255	255
150,000**	3,937	255	260	260	260

*Unclamped Spring Rate of 2,272 lb/in.

**Test completed, no apparent failures

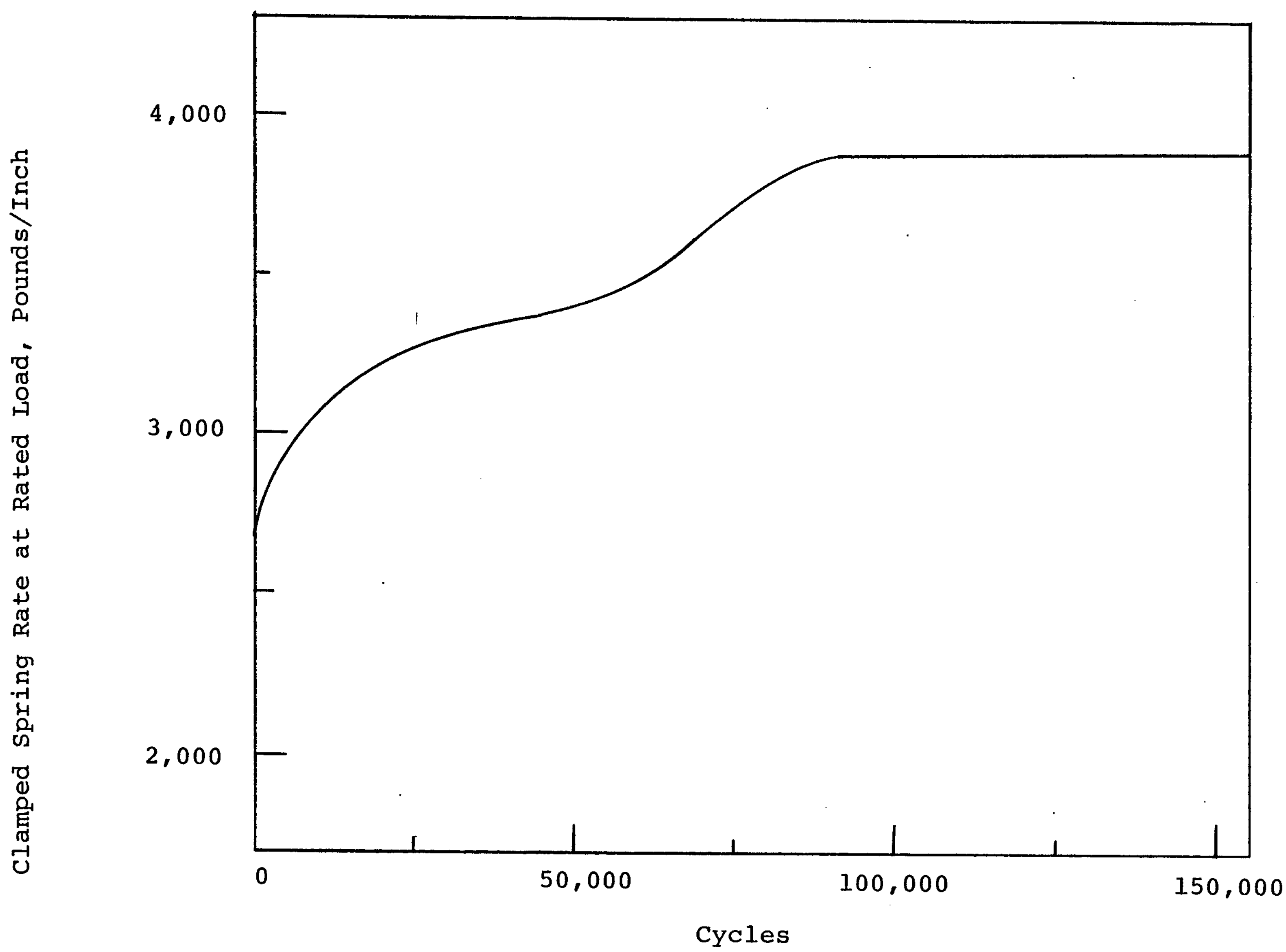


FIGURE 17 CLAMPED SPRING RATE AS A FUNCTION OF CYCLES FOR FRONT STEEL ASSEMBLY

Table 18

VERTICAL FATIGUE TEST RESULTS
FOR FRONT COMPOSITE ASSEMBLY S/N 1

Cycles	Clamped Spring Rate, lb/in. at Rated Load	Torque on U-Bolts lb-in.			
1	3,476*	260	260	260	260
10,000	3,346	180	220	200	180
35,000	3,522	200	215	225	230
60,000	3,566	230	255	250	230
85,000	3,544	260	245	265	260
110,000	3,522	260	245	255	260
135,000	3,588	260	255	260	265
150,000**	3,588	255	260	260	260

*Unclamped Spring Rate of 3,265 lb/in.
**Test completed, no apparent failures

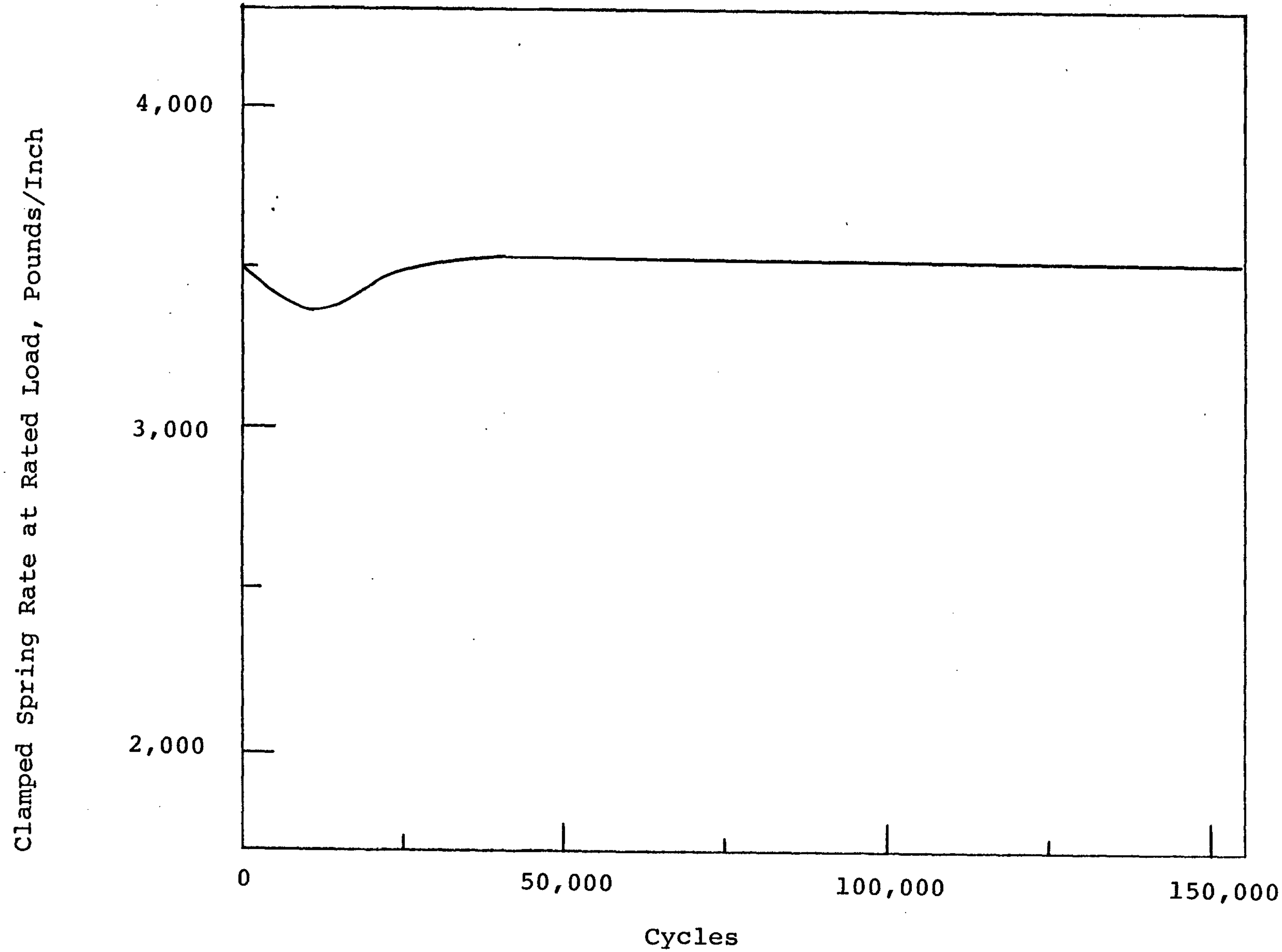


FIGURE 18 CLAMPED SPRING RATE AS A FUNCTION OF CYCLES FOR FRONT COMPOSITE ASSEMBLY S/N 1

Table 19

VERTICAL FATIGUE TEST RESULTS
FOR FRONT COMPOSITE ASSEMBLY S/N 2

Cycles	Clamped Spring Rate, lb/in. at Rated Load	Torque on U-Bolts lb-in.			
1	3,281	260	260	260	260
10,000	3,588	220	220	220	210
35,000	3,522	255	260	240	240
60,000	3,456	250	250	250	250
85,000	3,500	250	260	250	250
110,000	3,456	250	260	250	250
135,000	3,566	260	255	260	260
150,000*	3,500	260	260	260	260

*Test completed, no apparent failures

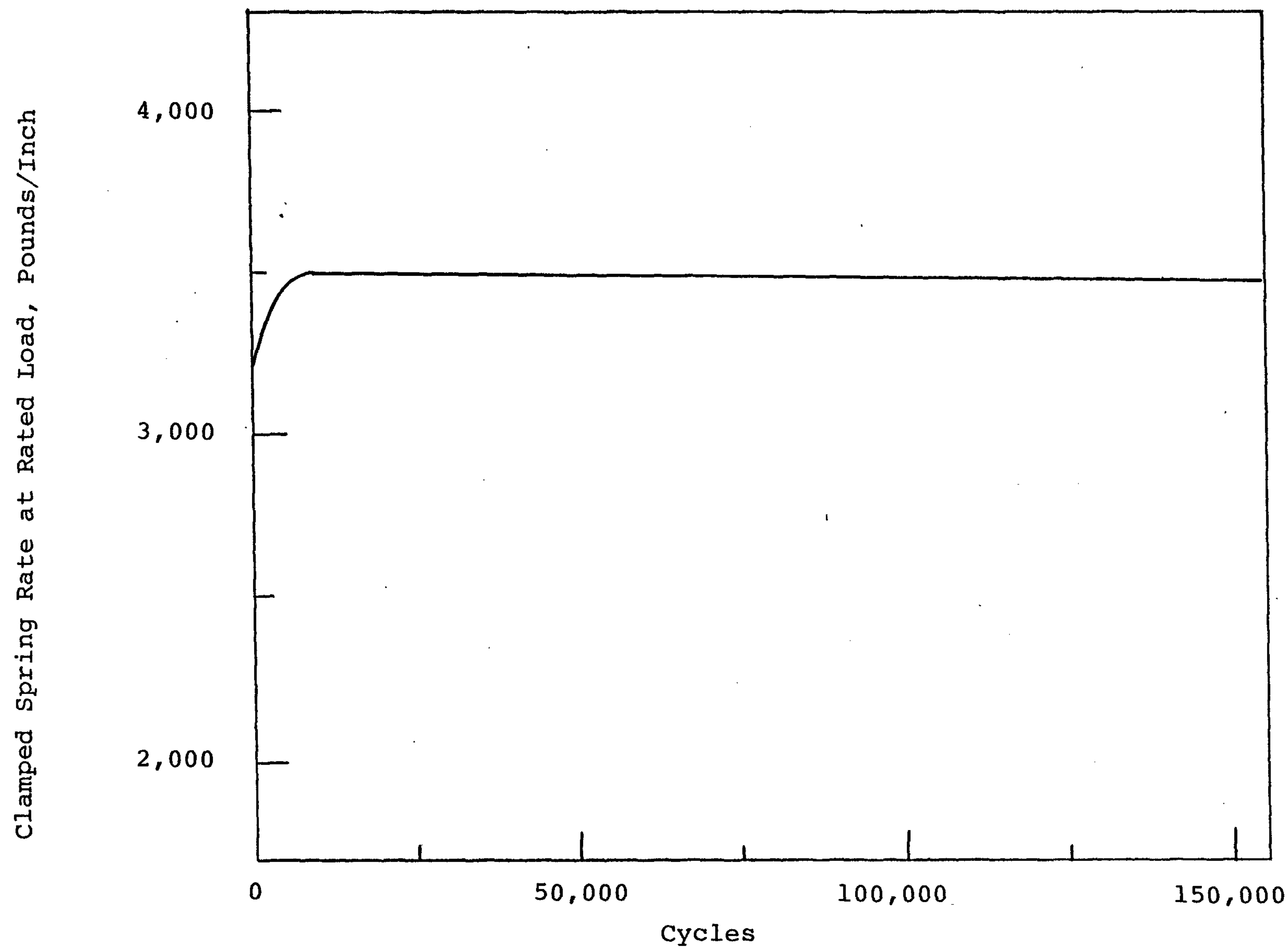


FIGURE 19 CLAMPED SPRING RATE AS A FUNCTION OF CYCLES FOR FRONT COMPOSITE ASSEMBLY S/N 2

Table 20

SUMMARY OF INITIAL SPRING RATES
FOR REAR SPRING ASSEMBLIES

Material	S/N	Clamped Spring Rate, lb/in. at Rated Load		
		Loading	Unloading	Average
Steel	---	7,437	6,694	7,065
Composite	1	6,038	5,381	5,710
	2	6,869	5,994	6,432
	3	7,394	6,213	6,804
	4	7,326	6,320	6,823
	5	7,364	6,475	6,920
	6	7,321	6,065	6,693
	Average	7,052	6,075	6,564

Table 21

VERTICAL FATIGUE TEST RESULTS
FOR REAR STEEL ASSEMBLY

Cycles	Clamped Spring Rate, lb/in. at Rated Load
1	7,437
10,000	10,588
35,000	11,375
60,000	11,113
85,000	11,681
110,000	11,419
135,000	11,594
150,000*	12,513

*Test completed, no apparent failures

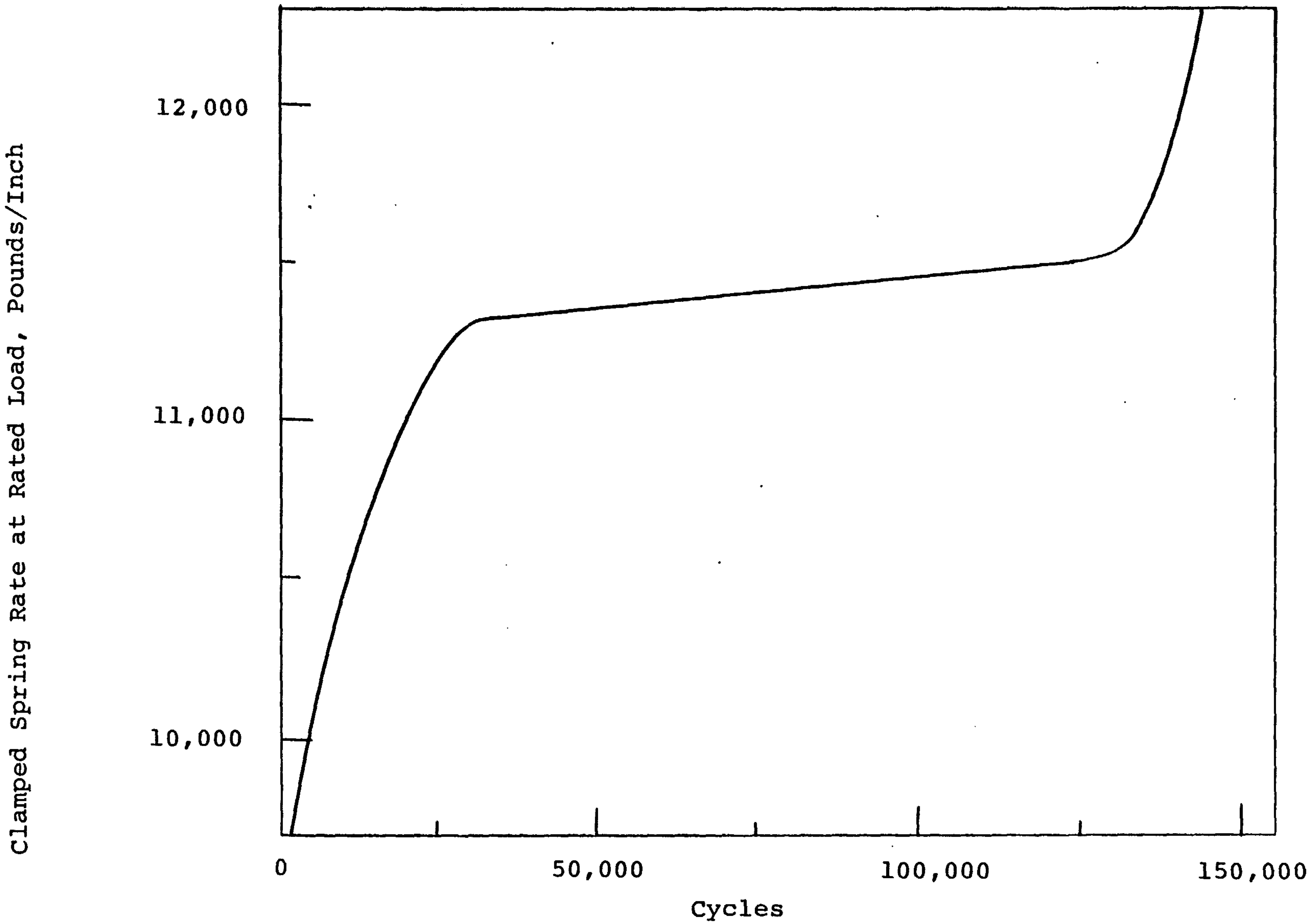


FIGURE 20 CLAMPED SPRING RATE AS A FUNCTION OF CYCLES FOR REAR STEEL ASSEMBLY

Table 22

VERTICAL FATIGUE TEST RESULTS

FOR REAR COMPOSITE ASSEMBLY S/N 1

Cycles	Clamped Spring Rate, lb/in. at Rated Load	Torque on U-Bolts lb-in.			
1	6,038	260	260	260	260
25,000	6,912	150	17	150	150
50,000	6,606	200	230	200	200
75,000	7,131	225	230	230	235
100,000	6,781	270	260	270	270
108,000*	---	---	---	---	---

*Steel main leaf broke

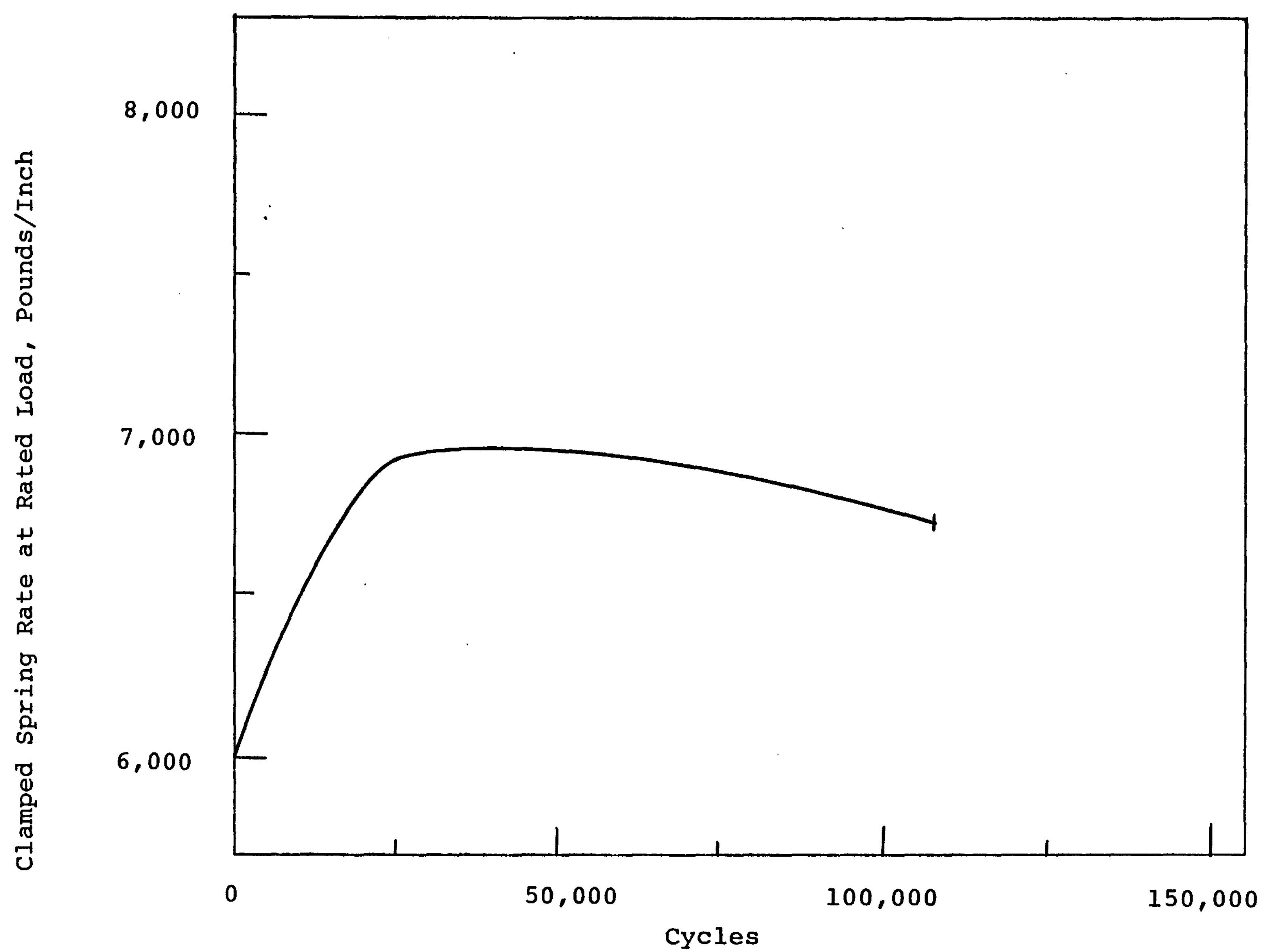


FIGURE 21 CLAMPED SPRING RATE AS A FUNCTION OF CYCLES FOR REAR COMPOSITE ASSEMBLY S/N 1

Table 23

VERTICAL FATIGUE TEST RESULTS
FOR REAR COMPOSITE ASSEMBLY S/N 2

Cycles	Clamped Spring Rate, lb/in. at Rated Load	Torque on U-Bolts lb-in.			
1	6,869	260	260	260	260
9,460*	6,388	---	---	---	---

*Test terminated: top composite leaf delaminated and vertical crack propagated from spacer edge

Table 24

VERTICAL FATIGUE TEST RESULTS

FOR REAR COMPOSITE ASSEMBLY S/N 3

Cycles	Clamped Spring Rate, lb/in. at Rated Load	Torque on U-Bolts lb-in.			
1	7,394	260	260	260	260
7,500*	---	---	---	---	---

*Test terminated: cracks formed in top composite leaf propagated to next two leaves

Static failure test results are shown below.

Composite Design to Replace P/N	Ultimate Torque, lb-in. Required	Experimental
8332248	57,270	81,800
11669147	78,000	111,000

These results are considered excellent.

Fatigue testing of the shafts showed that the adhesive bond failed. This was the result of the graphite tube shortening during loading; which is a result of the laminate characteristics. This shortening placed a positive transverse normal stress on the adhesive; adhesives have poor tensile strengths.

This phenomenon was observed during testing of the composite design to replace P/N 8332248; the fatigue life results are shown below.

Tube S/N	Fatigue Life, cycles
1	1,900
2	,40
3	2,400

A redesign to include a bolted and bonded joint between the composite tube and the steel end sleeves was undertaken. Changing the joint area was impossible because of the tube length; see Figure 10. Shafts to replace P/N 11669147 were fabricated to this new design and tested; the results are shown below.

Tube S/N	Fatigue Life, cycles
1	6,700
2	2,700

As shown, the bolts did not significantly change the results. The failure mode was not changed either. Therefore, it was decided to use only an adhesively bonded joint for the prototype parts.

The fatigue results were interpreted by Dana Corporation personnel to mean the following for the 5-ton Army truck:

-in peace time, probably indefinite life.
-in war time, where the truck is often in mud, a life expectancy of 9 months.

It was, therefore, decided to fabricate shafts to the proposed design for field testing.

6

BUDGETARY COST ESTIMATE FOR PRODUCTION

The following discussion assumes constant FY79 dollars for all cost calculations.

6.1 Leaf Spring Assemblies

6.1.1 Production Fabrication Process

For volume manufacturing, quantities of at least 25 units per day (6,250 per year) are required. For quantities of these amounts and greater, there are several manufacturing techniques which are applicable to the fabrication of composite leaf springs.

The primary objective in the fabrication of any component is to reduce to a minimum the number of processing steps and, in particular, those that require heavy labor content. The principle processing steps involved in the manufacture of a leaf spring are:

1. The deposition of material.
2. The curing of the component.
3. Assembly of the spring pack.

Of these, the first is a major contributor to the cost of composite hardware. It can range from a hand lay-up process in which plies are laid down individually to the rapid lay-down of material via a filament winding process. One of the primary considerations that determines which method is used is the type of material to be deposited and how rapidly it can be positioned to form the thickness and contour required by the product. Prepreg can be used and has the maximum flexibility in positioning the material. Depositing the same amount of material by filament winding would be faster; however, since the composite material leaf has a variable contour, the winding operation would have to be stopped several times to incorporate and position discrete plies in order to build up the variable contour. A compromise is to fabricate prepreg using a filament winding machine.

One of the solutions to the rapid deposition of material is to use thicker layers of reinforcement in order to reduce the number of pieces to be handled either by machine or by hand. Investigations have shown this to be the best trade-off in cost and in manufacturing rate. Two options are available. Unidirectional fiberglass can be used which will yield a per ply thickness between 0.020 and 0.030 inch. Or an XMC sheet molding compound material, which is available in thicknesses ranging from 1/8 to 1/4 inch, can be used.

The manufacturing processes that utilize these material forms are discussed below and are viable for the fabrication of composite leaf springs. They are state-of-the-art processes and satisfy the production rates required for this application.

a. Resin Injection Molding Fabrication Process

Resin injection molding involves the placement of dry reinforcement in a matched die cavity that is subsequently injected with liquid resin. The liquid resin is injected under pressure and, by also using a vacuum, it infiltrates the reinforcement held in the cavity. Once full injection has been accomplished, the die is heated to effect a cure. Figure 22 shows the process sequence.

It is not economical to use this process on a discrete leaf element. The proposed process is to fabricate a large billet, a minimum of 48 inches wide, to yield 12-15 discrete leaves. One cavity would be required for each of the leaf shapes in the assembly.

To use this method requires unidirectional fiberglass; this could be purchased in 48 inch widths or fabricated using a filament winding machine. This material would be cut to the prescribed pattern lengths and placed in the cavity dry. The resin can be any number of epoxy resin systems which exhibit low viscosity (for the resin injection) and combine with the glass reinforcement to produce a cured composite yielding the properties which are required of this application. Cure times for currently available resins range from 60 to 90 minutes. Newer resins now in the stage of advanced development and commercial application indicate cure times on the order of 10 to 20 minutes are possible.

After cure, the billets would be cut into discrete leaf elements using a profile cut-off saw programmed to cut the billet into the required width leaves. The ends of the leaves would then be trimmed to length, the center bolt hole drilled, the leaves inspected, and the discrete leaves assembled to form assemblies.

b. Compression Molding Fabrication Process

This process involves the matched metal molding of XMC sheet molding compound containing glass reinforcement and epoxy resin. The process sequence requires that individual patterns be cut from the broadgoods sheets and placed into the matched metal die. Again, these broadgoods sheets could be fabricated using filament winding. Under pressures of 500 to 1500 psi and temperatures from 300 to 400 degrees F, the part is cured in 10 to 20 minutes. It is then ejected from the mold, the centerbolt hole drilled, and the leaf inspected. Assembly into the spring pack would take place after these operations. Figure 23 shows this process.

Currently available XMC materials containing epoxy resins are in the advanced stages of development for some commercial applications. As a general rule they are available in thicknesses of 1/8 to 1/4 inch and have a cross-plied orientation of approximately 10 degrees. This orientation is appropriate for leaf spring applications. The material is received in a boardy (b-staged) condition which requires it to be heated in order to be formed into the complex

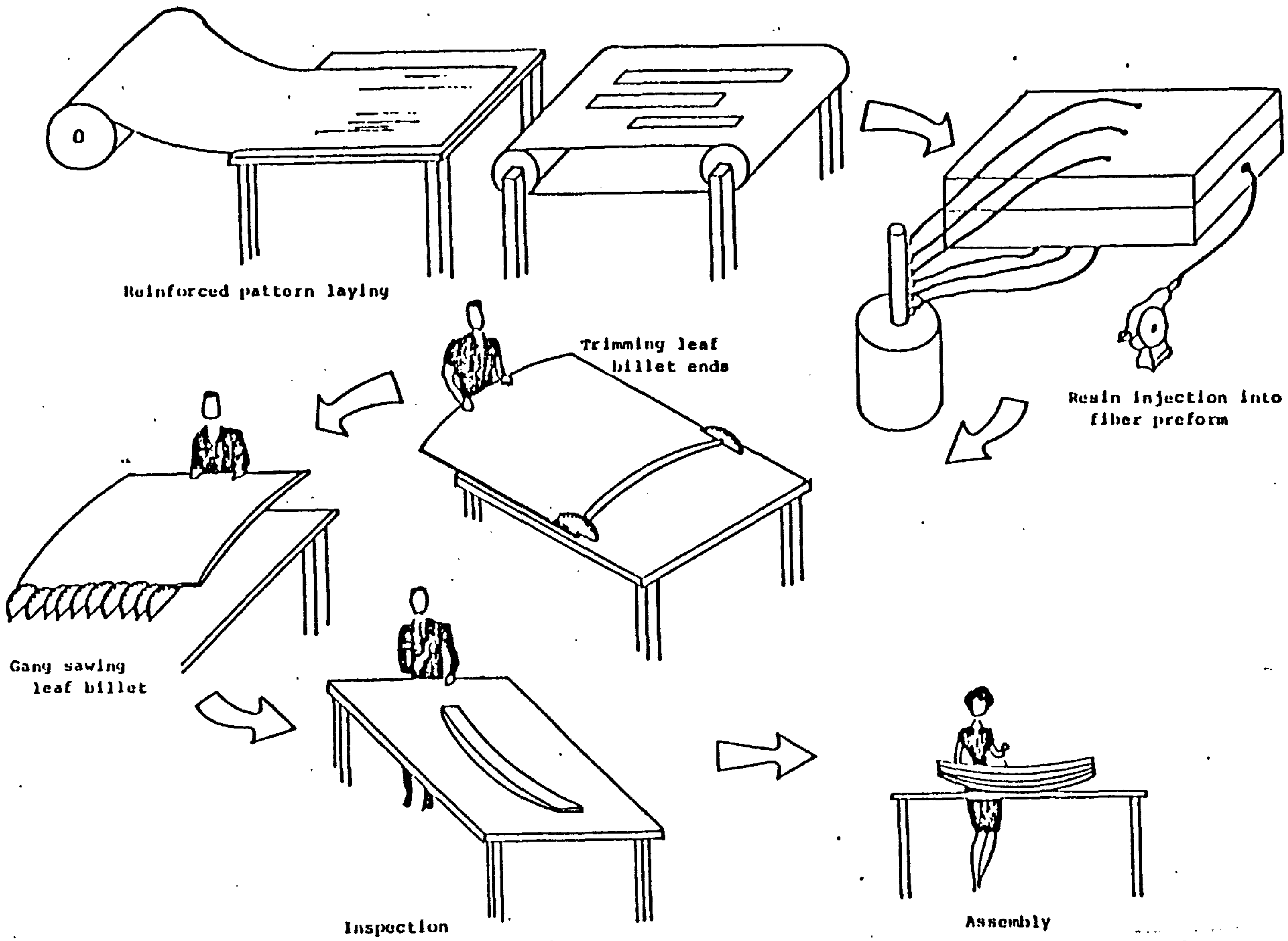


FIGURE 22. INJECTION MOLDING PROCESS

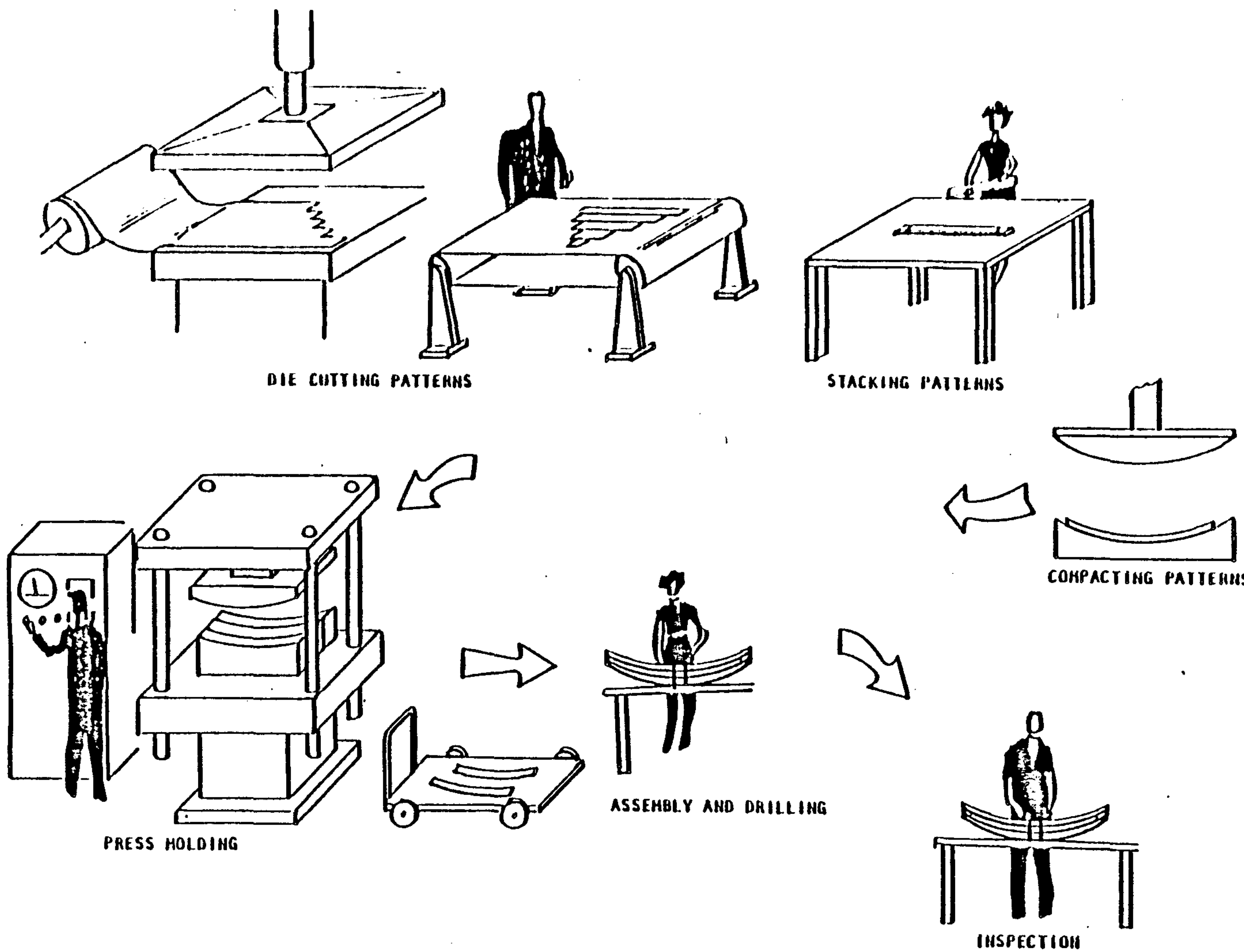


FIGURE 23. COMPRESSION MOLD PROCESS

contours of the leaf. Upon heating and with the application of pressure, it will flow and form readily to the leaf spring configuration. The compression molded part can be directly assemblied into a spring pack after removal of mold flash.

Curing of the currently available epoxy XMC molding compounds is accomplished at between 300 and 400 degrees F at pressures in excess of 500 psi. Cycle times range from 10 to 20 minutes depending on the system, thickness of the part, and the temperatures used. Present experience indicates that 15 to 20 minutes for currently available material is required to effect a cure on parts having the thickness required of heavy truck leaf springs.

There are two major concerns associated with using XMC molding compounds. The first is the distortion of the fiber orientation under the high pressure. This could result in a lower strength and stiffness than would occur from other processes. The second concern is that the thickness of the starting material is such that to retain uniform fiber and resin distribution in a variable contour build-up is difficult.

c. Chosen Fabrication Process

At the present time, the compression molding process is a tried and proven fabrication method for heavy truck leaf springs. The resin injection molding process offers some cost advantages; but still needs to be developed before it can be used as a production method. Therefore, for this study, the compression molding process has been chosen.

6.1.2 Non-Recurring Investment

The compression molding process requires a large press with a capacity of 100 to 300 tons. Such a press would cost $300,000 to $500,000. The work area required for production of leaf spring assemblies, except for the press, would be nominal. For this process, other required initial expenditures would be:

- the compression molds; one required for each leaf configuration
- centerbolt drilling fixture
- routing facilities

Compression molds for heavy truck leaf springs cost approximately $40,000 per mold. This includes the cost of design and fabrication of each mold. The other fixtures costs would be minimal in comparison. Thus, an estimate of initial mold cost is:

Spring Assembly	Number of Composite Leaves	Total Cost of Molds, Dollars
Rear	5	200,000
Front	2	80,000

One set of molds would be able to produce about 10,000 parts per year; the life of a mold should be in excess of 100,000 parts.

6.1.3 Production Costs

The compression molded process, once established, requires minimal supervision; most supervision would occur through quality control. Recurring engineering and sustaining tool costs are considered negligible.

The material costs associated with the spring assemblies are:

-fiberglass fiber in a compression moldable epoxy resin: this can be purchased for about $5 per pound. Rejection and/or scrap rate for this process in production is taken as 25%

-steel leaves, clips, riser plates, cnterbolts, etc: this can be assumed to cost $0.50 per pound

-miscellaneous materials (spacer and wear pads, adhesives, etc): the combined total per assembly is about $15.00

Labor charges, which are estimated from work performed at EEMD in the fabrication of compression molded leaf springs, are taken as:

-molding of leaf: 2 hrs of technician per leaf

-assembly: 2.5 hrs of technician per leaf

-Q.A.: 0.4 hrs of Q.A. technician

-supervision: 0.5 hrs of Engineer

There are no sub-contracted items associated with this process.

The budgetary cost estimate for production can be figured using the following process:

a. The total cost is calculated using the following elements

-Direct Labor Charges
-Labor Overhead at 140%

-Material Charges
-Material Handling Overhead at 12%
-Other Charges

b. The selling price is calculated by

-including 15% for general and administrative expenses
-including an 8% profit /fee

This results in

a. direct labor charges being multiplied by 2.13 to obtain the portion of the selling price due to labor

b. material charges being multiplied by 1.39 to obtain the portion of the selling price due to material

c. other costs being multiplied by 1.24 to obtain the portion of the selling price to these items

Using FY79 dollars and rates, these result in selling price labor rates of

Category	Burdened Labor Rate, Dollars/Hour
Technician	22.50
Q.A. Technician	19.50
Engineer	36.00

The burdened material costs are

Material	Burdened Cost, Dollars/Pound
Fiberglass-Epoxy	7.00
High-Strength Graphite-Epoxy	35.00
Epoxy Resin	8.00
Steel (in fabricated form)	0.70

For the leaf spring assemblies, the cost estimates are then:

	Rear Assembly		Front Assembly	
a. Material	pounds or hours	Burdened Cost, $	pounds or hours	Burdened Cost, $
Fiberglass-epoxy	70.7	495	23.4	164
Steel	74.1	52	46.5	33
Miscellaneous	----	21	----	21
TOTAL	----	568	----	218
b. Labor for 1st Unit				
		$		$
Technician	27.5	619	14.0	315
Q.A. Technician	0.4	8	0.4	8
Engineer	0.5	18	0.5	18
TOTAL	----	645	----	341
c. Subcontracts	----	0	----	0

To estimate the cost of a unit, the material costs shown above are to be used.

For estimating the labor hours associated with a unit, a learning curve is appropriate. Learning curves are predictive tools that must be applied with a great deal of professional judgement. Nevertheless, they are the manufacturing operations estimator's most powerful forecasting tool. They allow basic, standard time data to be used for estimating production quantities. The learning curve projects the actual time it will take to make units during the buildup to peak efficiency.

The learning curve concept is that as quantities double, the rate of learning remains the same.

Thus,

$$y = kx^{-n}$$

where

y = average cost per unit
x = number of units
k = cost of the first unit produced
n = constant, representing the relation between x and y

On a log-log plot, the learning curve is a straight line:

$$\log y = \log k - n \log x$$

Learning curves for machined or detailed parts are typically 95%. Subassembly learning curves are generally near 87% and minor assembly curves are about 86%. As unit complexity increases further, learning curve percentage continues downward.

For the truck components being considered in this study

-a learning curve of 90% is considered achievable
-a learning curve of 87.5% is considered possible
-a learning curve of 85% is considered overly optimistic

For the composite spring assemblies, the labor costs, in FY79 dollars, associated with each unit of production is shown in Figures 24 and 25. The initial unit cost is taken as that calculated above. To find the total cost of a production unit, the material and labor costs must be combined

6.2 Propeller Shafts

6.2.1 Production Fabrication Process

The fabrication process for the composite tube of the propeller shaft used in the prototype program is shown schematically in Figure 26. The female mandrel concept was employed for the reasons discussed in Section 4. However, this process does not lend itself to production: it is labor intensive.

Since the majority of the fibers are at a $\pm 45^\circ$ orientation, filament winding is the obvious choice for production of the composite tubes. For this process, the tooling is minimal, the fabrication process utilizes an automatable device which can easily apply fiber at a 45° angle, and no special curing equipment is required. Therefore, the filament winding process is chosen for the budgetary cost estimate for production.

6.2.2 Non-Recurring Investment

In addition to filament winding machines which are available in many composite fabrication facilities, only mandrels are needed to fabricate the composite tubes.

The mandrel would consist of a steel tube or shaft of constant diameter with machined slots to locate the end sleeves. Such a simple mandrel would cost $2,000 to $2,500. Production quantities would require the following number of mandrels:

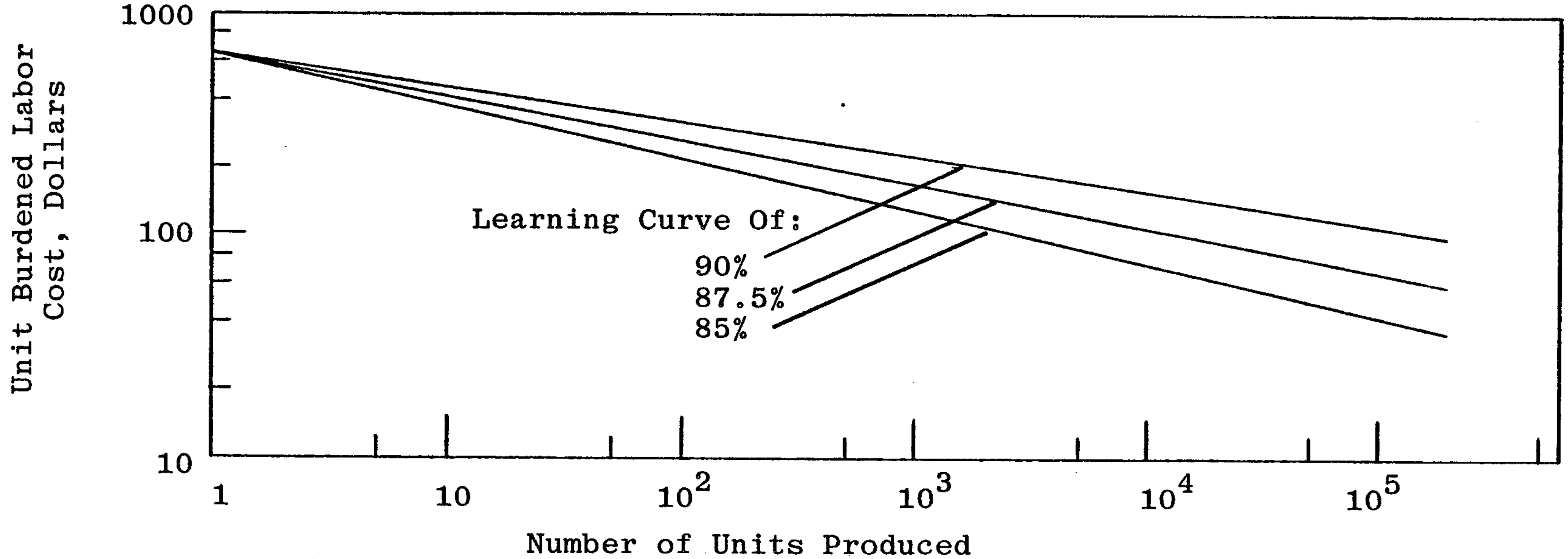


FIGURE 24 LEARNING CURVES FOR COMPOSITE REAR SPRING ASSEMBLY

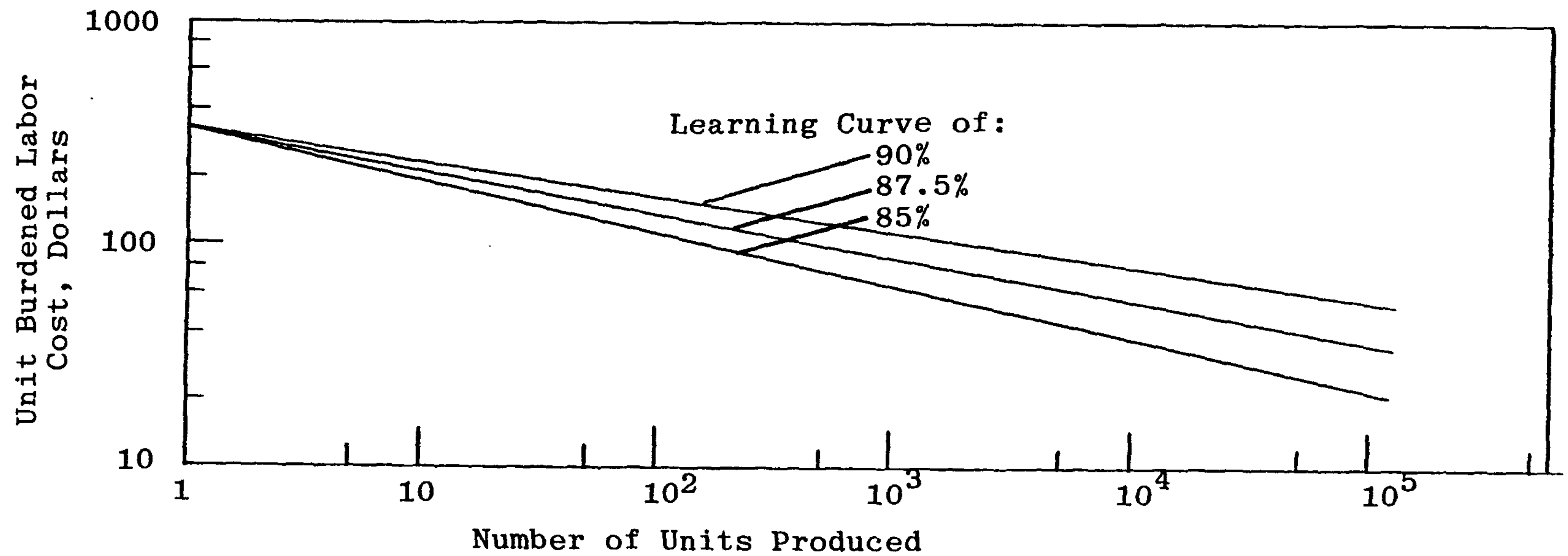
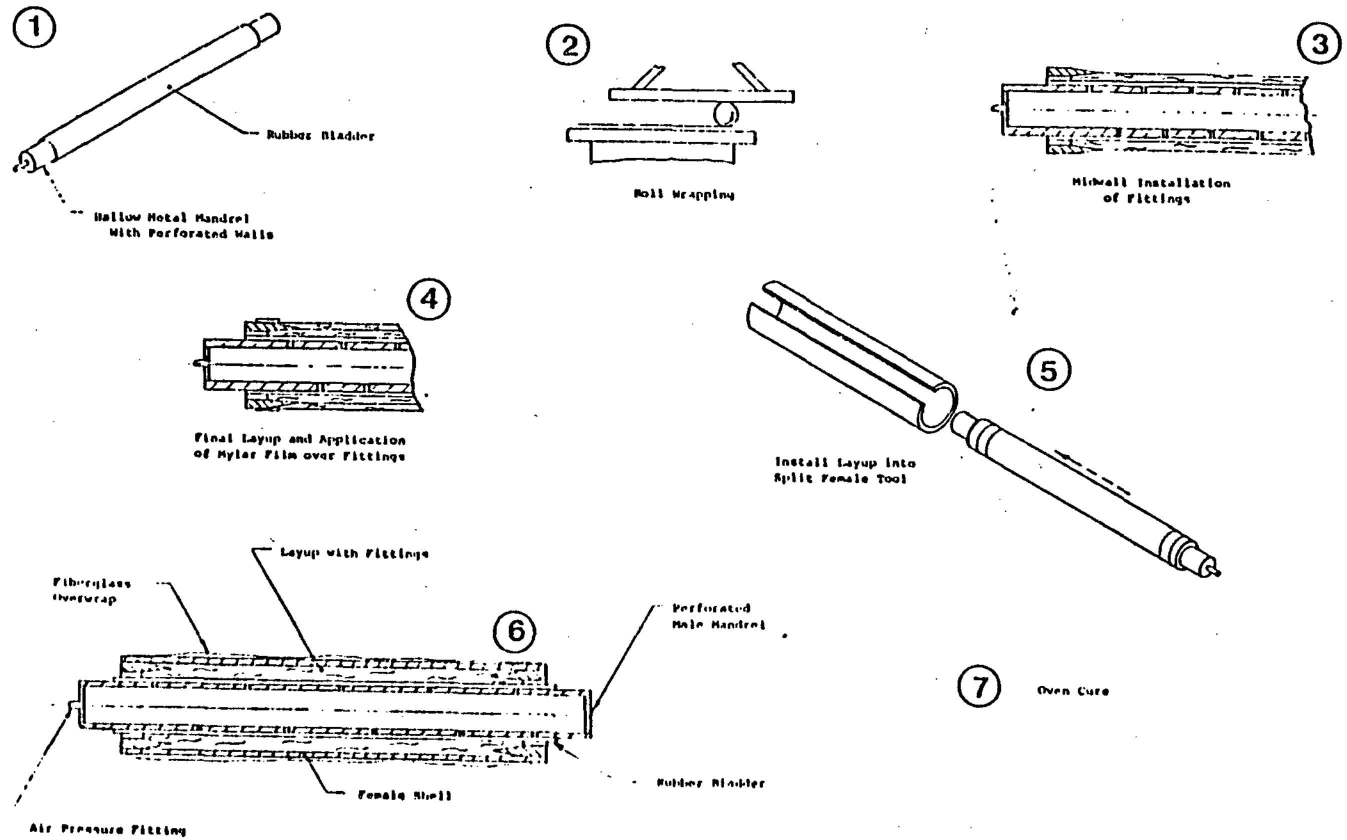
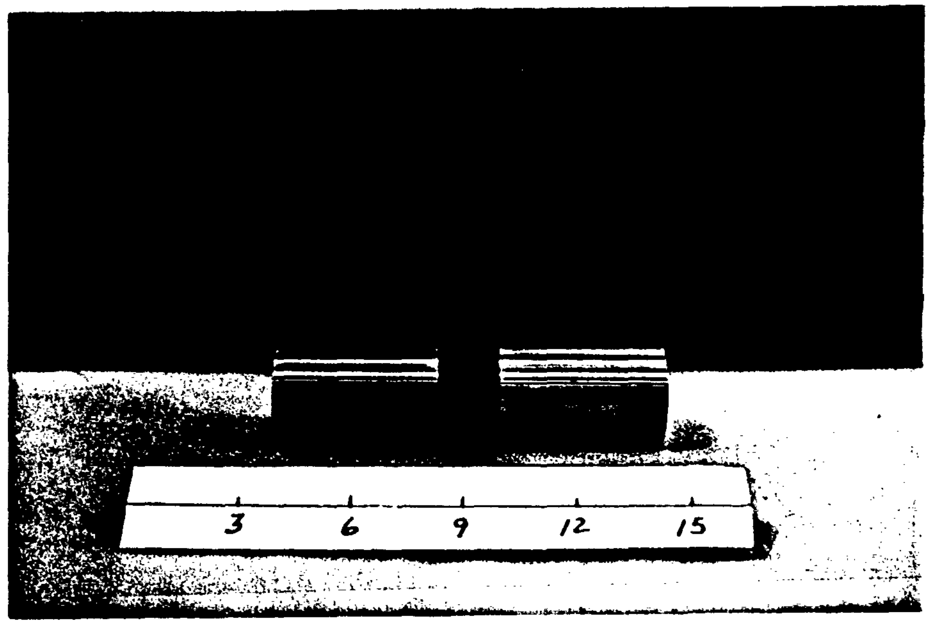


FIGURE 25 LEARNING CURVES FOR COMPOSITE FRONT SPRING ASSEMBLY



(a) Process

FIGURE 26 FABRICATION PROCESS FOR COMPOSITE TUBE



(b) Composite Tube

FIGURE 26 FABRICATION PROCESS FOR COMPOSITE TUBE

Yearly Production Rate	Number of Mandrels
1,020	10
5,100	36
10,200	68

A minimum economical yearly production rate would be 500.

Final machining of the cured tube would employ standard milling/cutting equipment.

6.2.3 Production Costs

The methods outlined in Section 6.1.3 can be used to obtain the budgetary cost estimates for the propeller shafts as well. The composite design replacing P/N 11669147 was chosen as the example for the propeller shafts since its length is near the average of the components considered. The cost estimate is:

(a) Material	Pounds or hours	Burdened cost, dollars
Graphite Fiber	2.75	96
Epoxy Resin	1.20	10
Steel Sleeves	3.0	2
Miscellaneous	----	2
TOTAL	----	110
(b) Labor for 1st Unit		
Technician	38	855
QA Technician	0.5	10
Engineer	0.4	15
TOTAL	----	880
(c) Subcontracts		
End fittings, Assembly, and Balancing (Existing technology used)	----	240

To estimate cost of a unit, use the material and subcontract costs shown above and the labor costs given in Figure 27.

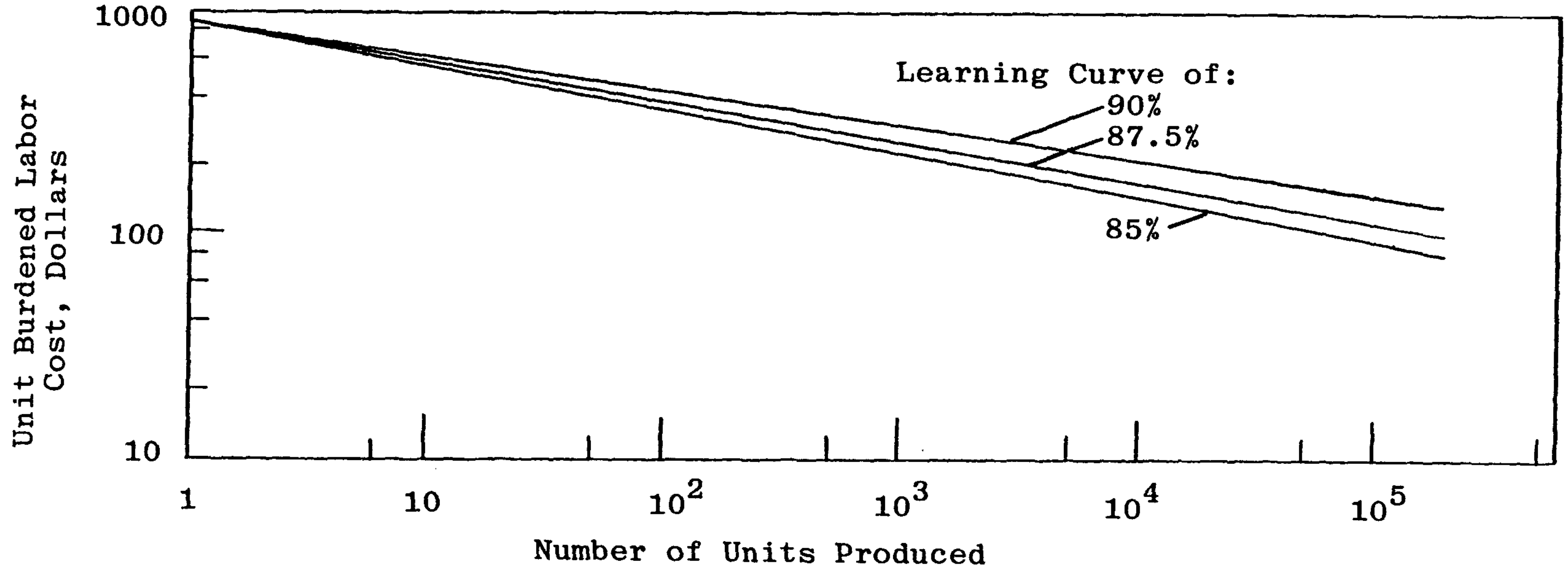


FIGURE 27 LEARNING CURVES FOR COMPOSITE TUBE

6.3 Estimated Production Costs

Estimated production costs for each component can be calculated from the data given in Section 6.1 and 6.2.

Table 25 gives the estimated production costs, neglecting non-recurring investment, for the 1,000th, 5,000th, and 10,000th unit produced.

TABLE 25

ESTIMATED PRODUCTION COSTS

Component		Estimated Cost, in Dollars, for 1,000th unit	5,000th unit	10,000th unit
Spring Assemblies:				
	Front	310	285	275
	Rear	890	715	685
Propeller Shafts:				
	P/N 11669147	845	570	535
	P/N 8332248	745	470	435

7
CONCLUSIONS AND RECOMMENDATIONS

The test results given in Section 5 indicate that the composite material components designed and fabricated as part of the program will meet the life requirements for these parts.

The cost data presented in Section 6 also indicate the economic benefits possible for these lightweight components. The next step in pursuing these conclusions are:

- -field testing of the prototype components
- -development of production processes for the components

APPENDIX A

FABRICATION PROCESS SHEETS
FOR LEAF SPRING

MANUFACTURING AND INSPECTION RECORD

Sheet 1 of 4
Part Number ________
Issue Number ________

FABRICATION OF REAR LEAF SPRING

Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Schdd. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
005	Record Lot Number and Expiration Date				
010	Clean Mold				
015	Cut Material				
020	Inspect Tool and Material for Cleanliness				
025	Lay-Up Material				
030	Vacuum Bag Material				
035	Lay-Up Material				
040	Vacuum Bag				
045	Cure Part and Record Data				
050	Cleanup and Secondary Work				
055	Inspection				

MANUFACTURING PROCESS SHEET

Part Number ________
Issue Number ________

Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
060	Remove prepreg from cold storage. Verify acceptance and shelf life.				
065	Clean tool being used with acetone or MEK. Allow to dry a minimum of 5 minutes at room temperature. Wipe entire lay-up surface with a clean rag saturated with RAM 225 release agent. (Repeat RAM 225 release procedure two more times.) Repeat cleaning operation for caul sheet also.				
070	Cut SP 250 E-Glass (GMS 1200) material to cutting spec. supplied by Engineering (attached sheet). Patterns are to be $\pm$ 5°. One plus pattern and one minus pattern constitute one ply. NOTE: Lengths of face sheets are cut 4 inches longer than the finished part. Tapered sheets are cut to the length specified on cut sheet. * See attached Figure 1 for ply cutting.				
075	<u>LayUp Procedure - Rear Spring</u>: Cut 2 lengths bleeder cloth 55" long x 32" wide. Cut 1 length TX1040 Separator 53 in. x 31 in. wide Lay down separator and bleeder cloth on the tool that is going to be used for fabrication. Bleeder will be laid down first, then separator.				
080	Start lay-up of $\pm$ 5° patterns cut in operation 070. Make sure during lay-up that no wrinkles occur. At mid-point of ply lay-up (Ply # 39), stop and compact part. <u>Compaction sequence is as follows:</u> 1) Cut a piece of TX1040 Separator about 1/4 in. to ½ in. larger than the part itself (approximate dimensions to cut 53 in. long x 34 in. wide) 2) Lay TX1040 Separator over part. (If any more than 1/2 in. to 3/4 in. of separator is lying on the tool, trim off) 3) Lay the caul sheet over part and separator. Use bag sealing compound at edges of caul sheet to protect bagging film (applied later) from puncture. 4) Place jute strips 3-1/2 in. wide around outside edges of part next to the tool. 5) Cut and place a layer of green 350°F bagging film around the whole part making sure bagging film lies beyond the jute.				

MANUFACTURING PROCESS SHEET

Part Number ______
Issue Number ______

Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
085	Cut a hole in the bagging film and place two vacuum fittings at two different areas of part. (Make sure vcuum areas are at opposite ends of part.) This will allow good vacuum pull. (Compaction is to debulk the part and remove trapped air.)				
090	Remove vacuum bagging material and continue lay-up from midpoint, Ply No. 40 final Ply No. 78.				
095	Cure Sequence: 1) Insert 3 TC leads into edge of part at various areas (one at each end, the other at center section). 2) Place TX1040 Separator over entire part with about 1/2 in. extra material around all of the part. 3) Place bleeder over separator using 5 pieces of bleeder the approximate size of the bleeder cloth. First 2 pieces - 57 in. long x 35 in. wide First tapered piece - 24 in. long x 35 in. wide Second tapered piece - 18 in. long x 35 in. wide Third tapered piece - 12 in. long x 35 in. wide				
100	Place caul cheet over bleeder and separator. Use 1/8 in Coroprene and construct a "cork dam" on the undersides of the caul sheet sides only. This is done to prevent a rollover of the part edges when vacuum is applied. * (Follow attached Figure A-3 for cork dam construction.) Cut a piece of 181 woven fiberglass. Lay it over caul sheet. Cut it long enough to cover ends, sides and onto tool about 1/2 in. Cut should be approximately 54 in. long x 35 in. wide. Use green 350°F bagging film and cover entire part down sides and ends beyond jute onto main tool itself. Use silicon rubber bag sealing compound to seal bag itself. Pull vacuum on part at a minimum of 25Hg. Part to be checked for vacuum leaks.				

MANUFACTURING PROCESS SHEET

Part Number ____________
Issue Number ____________

Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
105	Place in large autoclave at room temperature. Cure Conditions: Apply 85 psi. Heat to 200°F part temperature. Hold for 30 minutes. Heat to 250°F. Hold for 1 hour. Shut off autoclave. Cool under pressure.				
110	Remove from autoclave and debag. With a white marking pencil, draw the centerline on top of the spring. Take it to Machine Shop for trim.				
115	Have Machine Shop cut spring width per the drawing (49.00 in. x 4.00 in. ± 0.030 in.).				
120	Take part to Q.C. for inspection.				
125	Take part to Test Lab for static rate check.				
130	Test Lab send spring back to Prototype Lab for assembly operation.				

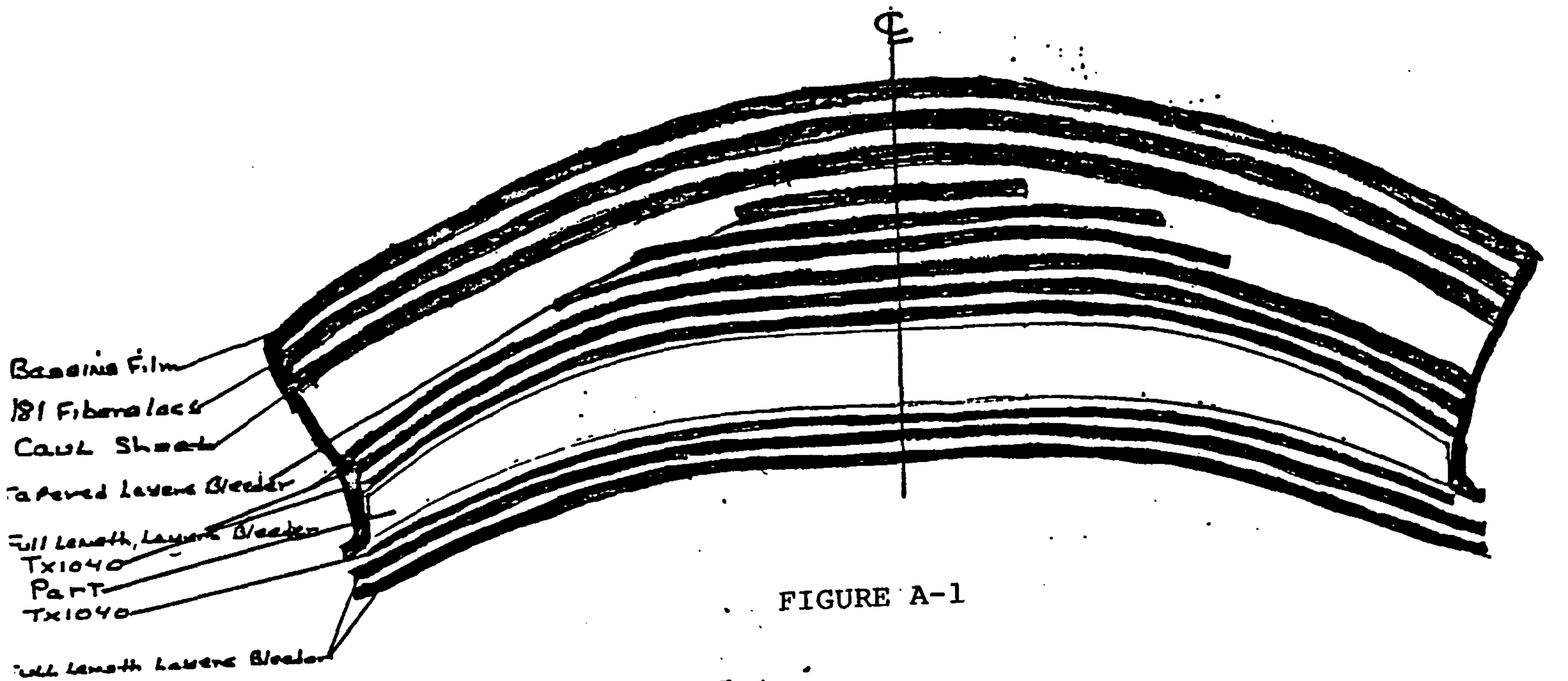


FIGURE A-1

Bagging Technique

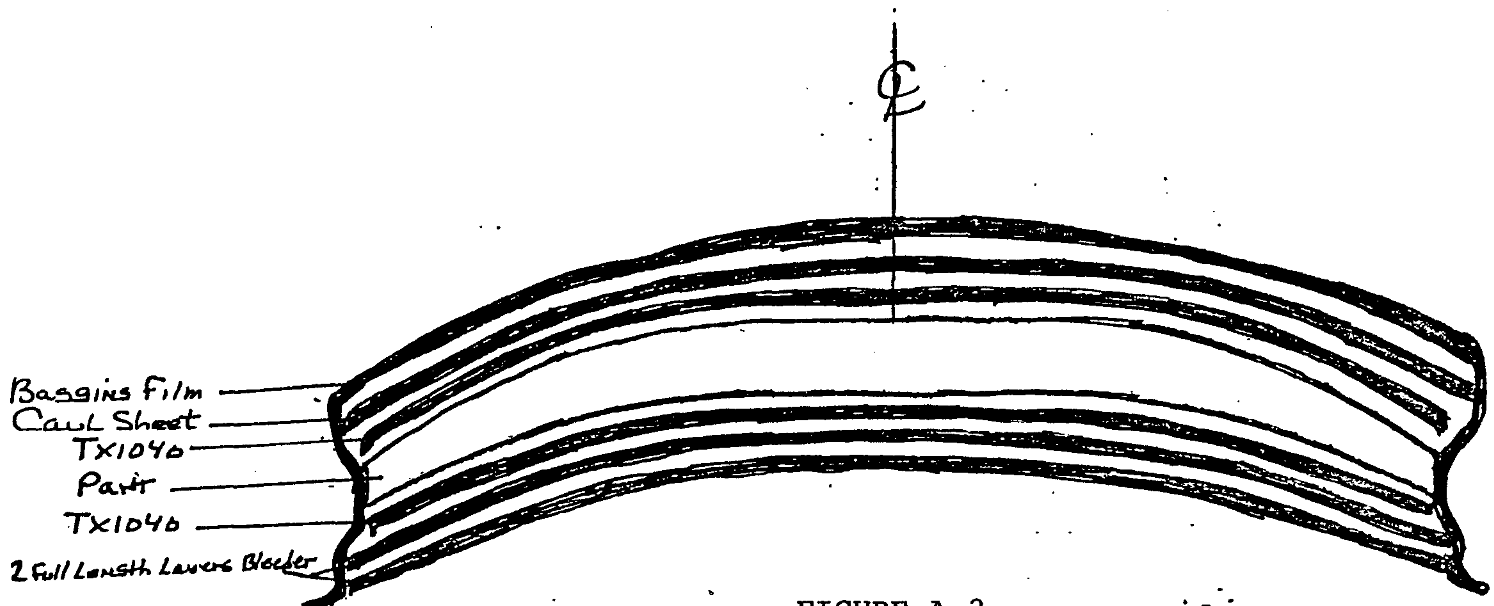


FIGURE A-2

Compaction Technique

TACOM REAR LEAF SPRING / 386 / JUNE 9, 1980

---------------------------INDIVIDUAL PLY LENGTHS-----------------PAGE 1

PLY THICKNESS IS 0.0166 INCHES

PLY NUMBER	FRONT LENGTH	REAR LENGTH	TOTAL LENGTH
1	24.00	24.00	54.00
2	24.00	24.00	54.00
3	24.00	24.00	54.00
4	24.00	24.00	54.00
5	24.00	24.00	54.00
6	24.00	24.00	54.00
7	24.00	24.00	54.00
8	24.00	24.00	54.00
9	24.00	24.00	54.00
10	24.00	24.00	54.00
11	24.00	24.00	54.00
12	24.00	24.00	54.00
13	24.00	24.00	54.00
14	24.00	24.00	54.00
15	24.00	24.00	54.00
16	24.00	24.00	54.00
17	24.00	24.00	54.00
18	24.00	24.00	54.00
19	24.00	24.00	54.00
20	24.00	24.00	54.00
21	24.00	24.00	54.00
22	24.00	24.00	54.00
23	17.20	17.20	34.40
24	16.40	16.40	32.80
25	15.80	15.80	31.60

TACOM REAR LEAF SPRING / 386 / JUNE 9, 1980

----------------------------INDIVIDUAL PLY LENGTHS-----------------PAGE 2

PLY THICKNESS IS 0.0166 INCHES

PLY NUMBER	FRONT LENGTH	REAR LENGTH	TOTAL LENGTH
26	15.20	15.20	30.40
27	14.70	14.70	29.40
28	14.20	14.20	28.40
29	13.80	13.80	27.60
30	13.40	13.40	26.80
31	13.00	13.00	26.00
32	12.60	12.60	25.20
33	12.20	12.20	24.40
34	11.90	11.90	23.80
35	11.60	11.60	23.20
36	11.20	11.20	22.40
37	10.90	10.90	21.80
38	10.60	10.60	21.20
39	10.30	10.30	20.60
40	10.00	10.00	20.00
41	9.70	9.70	19.40
42	9.50	9.50	19.00
43	9.20	9.20	18.40
44	8.90	8.90	17.80
45	8.70	8.70	17.40
46	8.40	8.40	16.80
47	8.20	8.20	16.40
48	7.70	7.70	15.40
49	7.40	7.40	14.80

TACOM REAR LEAF SPRING / 386 / JUNE 9, 1980

----------------------------INDIVIDUAL PLY LENGTHS------------------PAGE 3

PLY THICKNESS IS 0.0166 INCHES

PLY NUMBER	FRONT LENGTH	REAR LENGTH	TOTAL LENGTH
50	7.20	7.20	14.40
51	7.00	7.00	14.00
52	6.70	6.70	13.40
53	6.50	6.50	13.00
54	6.10	6.10	12.20
55	24.00	24.00	54.00
56	24.00	24.00	54.00
57	24.00	24.00	54.00
58	24.00	24.00	54.00
59	24.00	24.00	54.00
60	24.00	24.00	54.00
61	24.00	24.00	54.00
62	24.00	24.00	54.00
63	24.00	24.00	54.00
64	24.00	24.00	54.00
65	24.00	24.00	54.00
66	24.00	24.00	54.00
67	24.00	24.00	54.00
68	24.00	24.00	54.00
69	24.00	24.00	54.00
70	24.00	24.00	54.00
71	24.00	24.00	54.00
72	24.00	24.00	54.00
73	24.00	24.00	54.00
74	24.00	24.00	54.00
75	24.00	24.00	54.00
76	24.00	24.00	54.00
77	24.00	24.00	54.00
78	24.00	24.00	54.00

FABRICATION PROCESS SHEETS

FOR LEAF SPRING ASSEMBLY

MANUFACTURING AND INSPECTION RECORD

Mfg/Job Order No. 386

Quantity

Start and Finish Schedule

S/N Effectivity

Part Number 10031

Description TACOM Leaf Spring Assembly (Front)

Issue Number 1

E. Schauer 11/80	[illegible] 10/31/80	
Prepared By - Date	Approved By - Date	Q.A. Review - Date

Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
035	Inventory of Spring Components				
030	Preparation of Metal Leaf				
025	Preparation of Composite Leaf				
020	Bonding of Pads and Spacers				
015	Inspection				/
010	Assembly of Springs				
005	Inspection				

MANUFACTURING PROCESS SHEET

Mfg/Job Order No. 386

Quantity ______

Start and Finish Schedule ______

S/N Effectivity ______

Part Number 10031

Description TACOM Leaf Spring Assembly (Front)

Issue Number 1

E. Schauer 11/80 — Prepared By - Date

JJS 10/31/80 — Approved By - Date

Q.A. Review - Date

Material Requirements:

Specification	Description	Amount/Assembly	Total/Part
10031-1	Steel Leaf No. 1	1	
10031-2	Steel Leaf No. 2	1	
10031-3	Composite Leaf No. 3	1	
10031-4	Composite Leaf No. 4	1	
50000 1	TFE Polyester Fabric; also Wear Pad	8 of each	
	GIDS Board Wear Spacer	3	
	Line Clip	2	
	7/16 inch x 14 inch Nut	2	
	1/2 inch x 5 inch Bolt	1	
	1/2 inch x 20 inch Nut	1	
612115-001	Hysol EA-8 Adhesive	12 grams	
612111-001	Hysol 934 Adhesive	90 grams	
612103-001	3M EC 3532 Adhesive	83 grams	
	MEK	As Required	
	Aluminum Bond Plates	8	
	C-Clamps	8	
	Bonded Clip Bracket	2	

Special Instructions:

1) Make sure Pads and Spacers are dry and completely bonded before starting assembly.

MANUFACTURING PROCESS SHEET

Sheet 3 of 13
Part Number 10031
Issue Number 1

Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
030 663-02	Clean off large wooden table. Locate all materials needed to bond pads and spacers. (Check materials requirements list.)				
030 663-02	Metal Leaf: Leaf Number 2 (Figure A3) With a scribe, mark a line 7 inches from both ends of the spring (flat side of spring). Do this with all No. 2 leaves that are to be assembled.				
030 663-02	Take leaves to sand-blasting machine. Sand blast appropriate 7 inch area making sure surface is smooth and free of paint. When completed, bring leaves back to work area.				
030 663-02	Leaf Number 1: Top Side (Figure A4) With a sharp scribe, mark a line (at both ends) 4 inches in from centerline of bushing hole. Sand blast entire 4 inch area making sure surface is smooth and free of paint. When completed, bring leaves back to work area.				
030 663-02	Using clean cloth, wipe entire top and bottom surfaces of both metal leaves (Numbers 1 and 2) with MEK. Allow to dry. Place clean metal leaves in an undisturbed area (preferably under table). Cover with clean cloth.				
025 663-02	Composite Leaves: Numbers 3 and 4 Using clean cloth, wipe entire top and bottom surfaces of composite leaves using MEK. Allow to dry. Place clean composite leaves in an undisturbed area. Cover with clean cloth.				
025 663-02	Secure sheet of TACOM wear pad material (P/N 500001). Cut wear pads as shown on FigureA3. (There are 8 wear pads 5 inches long x 3 inches wide needed per front spring assembly.) Wear pads will be cut in machine shop on vertical band saw. After wear pads are cut to size, clean "fuzzy" cut edge by rubbing 400 grit sandpaper lightly 1 or 2 times across cut surface. Wipe clean with cloth. Stack neatly on clean area of work bench. Important: Cut and clean enough wear pads to assemble six springs.				

MANUFACTURING PROCESS SHEET

Sheet 4 of 13
Part Number 10031
Issue Number 1

Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
025 663-02	Secure sheet of G10 board wear spacer material. Cut wear spacer material as shown in Figure A6. There are 3 wear spacers 8 inches long x 3 inches wide needed per front spring assembly. Wear spacers will be cut in machine shop on vertical band saw. Tapered ends (per Figure A6) will also be ground in machine shop. After spacer pads are cut to size and ends ground, clean "fuzzy" cut edge by rubbing 400 grit sandpaper lightly 1 or 2 times across cut surface. Wipe clean with cloth. Stack neatly on clean area of work bench. Important: Cut and clean enough wear spacers to assemble complete order.				
025 663-02	Locate 104 woven fiberglass "scrim cloth." (Spec - 620002). Cut the following quantities of "scrim cloth" to the appropriate given dimensions: 2 pieces - 1-3/4 inches wide x 3 inches long 8 pieces - 3 inches wide x 5 inches long 3 pieces - 3 inches wide x 8-1/2 inches long (This is enough for one assembly.) Cut enough cloth to assemble complete order. Bring cut material to work bench and stack in a clean area, easily accessible.				
020 663-02	Bonding Sequence: Secure metal leaves 1 and 2. Place on work table. Allow adhesive to warm to room temperature. * Starting with Leaf 1, mix required amount of Hysol EA-8 adhesive, enough do do all No.1 leaves. Mix material in a clean dry container. (Weigh appropriate A & B part amounts on Gram Weighing Scale located in the main Shop area.): Ratio 100 parts A, 6 parts B. Mix 150 grams A, 9 grams B.				
020 * 663-02	Apply EA-8 Adhesive on top side of leaf 1 in a 1-1/2 inch area (Figure A2). Put already cut 104 woven fiberglass "scrim cloth" over appropriate area per Print 10031. Work adhesive into scrim cloth with a squeegee until cloth is saturated				
020 663-02	Place Leaf 1 bonded clip onto appropriate area per Print 10031. Clamp bonded clip to spring with C-Clamp. Do this for all 6 front spring assemblies. Place all No. 1 bonded leaves in a protected area (preferably under work bench). Cover springs with a clean cloth. Discard remaining adhesive mixture and all used containers, etc..				

MANUFACTURING PROCESS SHEET

Part Number 10031
Issue Number 1

Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
020 663-02	Place all No.2 leaves on top of work bench. Turn spring so that flat surface is up (Figure A3) Allow adhesive to warm to room temperature. * Mix required amount of Hysol 934 (100) Part A to 33 Part B by weight. Mix enough to bond for all spring assemblies (2 pads per assembly) -- 133 grams total 934 adhesive for all spring assemblies. Spread adhesive in an area that will cover entire wear pad surface. Adhesive area should coincide with wear pad placement per Print 10031. Place scrim cloth over appropriate area and work adhesive into cloth until saturated. Place pad in precise location (per Print 10031). Cover pad with cut piece of aluminum. With C-Clamp, tighten down aluminum onto steel leaf. Do this at both ends, for all No.2 leaves.that are to be assembled. Discard remaining adhesive and containers. (Pot life of Hysol 934 is 30 minutes.)				
020 663-02	When all No.2 leaves are complete, put all No. 1 leaves and all No. 2 leaves in oven with the following cure: Minimum of 90 minutes at 200°F $\pm$ 10°F. When cure is complete, shut off oven. Allow springs to cool to room temperature. Take springs out of oven.				
020 663-02	Store springs on floor underneath work bench. Cover with clean cloth.				
020 663-02	Be careful not to touch end areas, place all No. 3 composite leaves on table top. Wipe affected wear pad areas (per Print 10031) with MEK. Wipe with clean cloth. Allow to dry.				
020 663-02	Mix at one time the required amount of Hysol 934 to bond needed amount of pads for 3 No.3 leaves (12 pads). (The pot life of Hysol 934 is 30 minutes.) 100 Part A to 33 Part B -- 133 grams for 3 No. 3 leaves. Spread adhesive on front and back sides of 1/2 of No. 3 leaf. Adhesive should be spread on area to coincide with wear pad placement. Place cut scrim cloth pieces on appropriate area. Place wear pad over scrim cloth. Do this for both sides of leaf No. 3 per Print 10031.				
020 663-02	Clamp cut aluminum backing pieces to wear pads with C-Clamp. Proceed with second half of Leaf No.3 in an identical manner. Do this for 3 No. 3 leaves.				

MANUFACTURING PROCESS SHEET

Part Number 10031
Issue Number 1

Oper No / Mfg No / Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
020 / 663-02	When 3 leaves are completed, mix a new identical amount of Hysol 934 to complete the remaining 3 leaves. When Hysol 934 is ready, proceed with wear pad bonding as was done for first 3 No.3 leaves.				
020 / 663-02	When all No.3 leaves are completed, stack under work table to avoid damage.				
020 / 663-02	Place all No.4 leaves on table top. Be careful not to touch springs at ends near wear pad areas. Wipe affected wear pad areas (per Print 10031) with MEK. Wipe with clean cloth. Allow to dry.				
020 / 663-02	Mix at one time the required amounts of Hysol 934 to bond appropriate amount of pads for 3 No.4 leaves (6 pads). (The pot life of Hysol 934 is 30 minutes.) 50 grams Part A to 16.5 grams Part B -- 66.5 grams for 3 No.4 leaves. Spread adhesive on appropriate side of No.4 leaf at both ends (per Print 10031). Adhesive should be spread on area to coincide with wear pad placement. Place cut scrim cloth pieces on appropriate area. Work adhesive into scrim material until saturated. Place wear pad over scrim cloth. Do this for both ends of Leaf No. 4.				
020 / 663-02	Clamp cut aluminum backing pieces to wear pads and backside of composite part with 4 inch C-Clamp, tightly. Do this for 3 No.4 leaves.				
020 / 663-02	When 3 leaves are completed, mix a new identical amount of Hysol 934 to complete the remaining 3 leaves. When Hysol 934 is ready, proceed with wear pad bonding as was done for first 3 No.3 leaves. When all No.4 leaves are completed, put all No.3 and No.4 leaves in oven and cure as follows: Minimum of 90 minutes at 200°F ± 10°F.				
020 / 663-02	After cure cycle is completed, shut off oven. Allow leaves to cool down in oven to room temperature. Remove all leaves and place on top of work table.				
020 / 663-02	Start with No.3 composite leaves. Clean affected center area of all No.3 composite leaves.				

MANUFACTURING PROCESS SHEET

Part Number 10031
Issue Number 1

Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
020	Allow adhesive to warm to room temperature. Mix required amount of EC 3532 adhesive to bond needed amount of wear spacers for 3 No.3 leaves (3 spacers). 50 Part A to 50 Part B -- 100 grams for 3 No.3 leaves. (The pot life of EC 3532 is 7 minutes.)				
020 663-02	Spread adhesive on appropriate area to coincide with wear spacer placement. Place cut scrim cloth pieces on appropriate area (per Print 10031). Work adhesive into scrim cloth until cloth is saturated. Place wear pad over scrim cloth. Clamp cut aluminum backing pieces with C-Clamp.				
020 663-02	When 3 leaves are completed, mix a new identical amount of EC 3532. This will complete the remaining 3 leaves.				
020 663-02	When EC 3532 is ready, proceed with wear spacer bonding as was done for first 3 No.3 leaves.				
020 663-02	When 6 No.3 leaves are completed, stack under work table to avoid damage and allow to cure at least 2 hours at room temperature.				
020 663-02	Number 4 Composite Leaves: Clean affected center area of all 6 No.4 composite leaves.				
020 663-02	Mix required amount of EC 3532 adhesive to bond needed amount of wear spacers for 3 No.4 leaves (6 spacers). 75 Part A to 75 Part B -- 150 grams for 3 No.4 leaves. (The pot life of EC 3532 is 7 minutes.)				
020 663-02	Spread adhesive on appropriate area to coincide with wear spacer placement. Place cut scrim cloth pieces on appropriate area (per Print 10031). Work adhesive into scrim cloth until cloth is saturated. Place wear pad over scrim cloth. Clamp cut aluminum backing pieces with C-Clamp on both sides of approp-riate center section of Leaf No. 4.				
020 663-02	When 3 leaves are completed, mix a new identical amount of EC 3532. This will complete the remaining 3 leaves.				

MANUFACTURING PROCESS SHEET

Sheet 8 of 13
Part Number 10031
Issue Number 1

Oper No / Mfg No / Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
020 / 663-02	When 3M 3532 adhesive is ready, proceed with wear spacer bonding as was done for first 3 No.4 leaves.				
020 / 663-02	When all No.4 leaves are completed, stack under table. Allow to cure at least 2 hours at room temperature.				
020 / 663-02	After all pads are cured, remove remaining C-Clamps.				
020 / 668-02	Remove any excess adhesive with rotary wire wheel.				
015 / 668-02	Visually inspect parts.				
010 / 663-02	Assembly Process: Stack all metal and composite leaves on work bench top. Assemble metal and composite leaves as shown in Figure A7.				
010 / 663-02	After leaves have been stacked (per Figure A7 insert front spring U-Clips into appropriate bonded-in clip holder. Tighten down nuts on threaded U-Clip ends. (There are 2 U-Clips and 2 clip holders per assembled spring.) NOTE: There is a 1/2 inch gap between bottom of composite leaf 4 and surface of U-Clip itself. During Machine Shop drilling, put a wooden spacer in gap area. This will assure no movement occurs between leaves during drilling.				
010 / 663-02	Take assembled springs to Machine Shop.				
010 / 662-02	Machine Shop to set assembled springs in special drilling fixture. Drill center hole (per Print 10031).				
010 / 662-02	Center bolt inserted and tightened in Machine Shop. Wooden spacers to be taken out.				
010 / 662-02	Parts to be air-blown clean of any metal or glass chips.				
005 / 668-02	Parts to be taken to Q.C. Inspection Area for final visual inspection.				

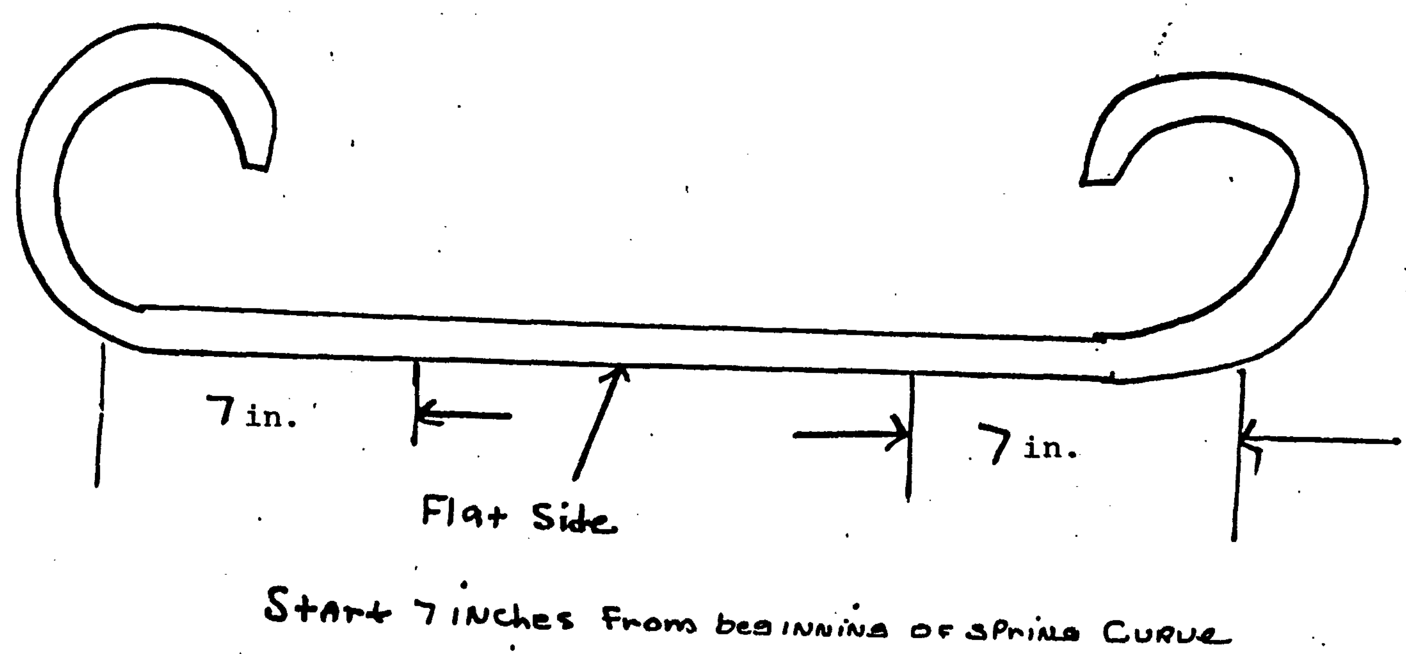


FIGURE A3

Front Spring Leaf No. 1

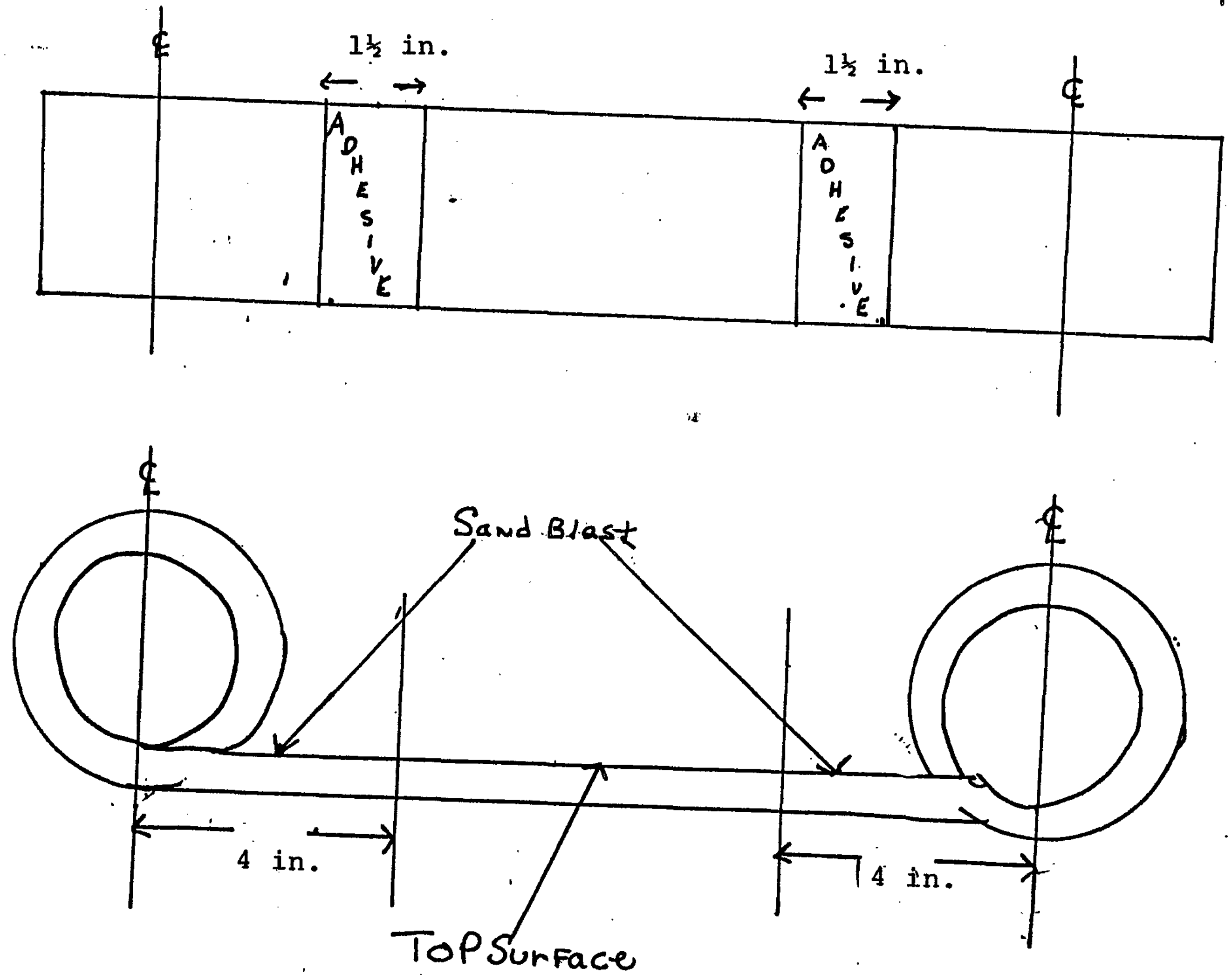
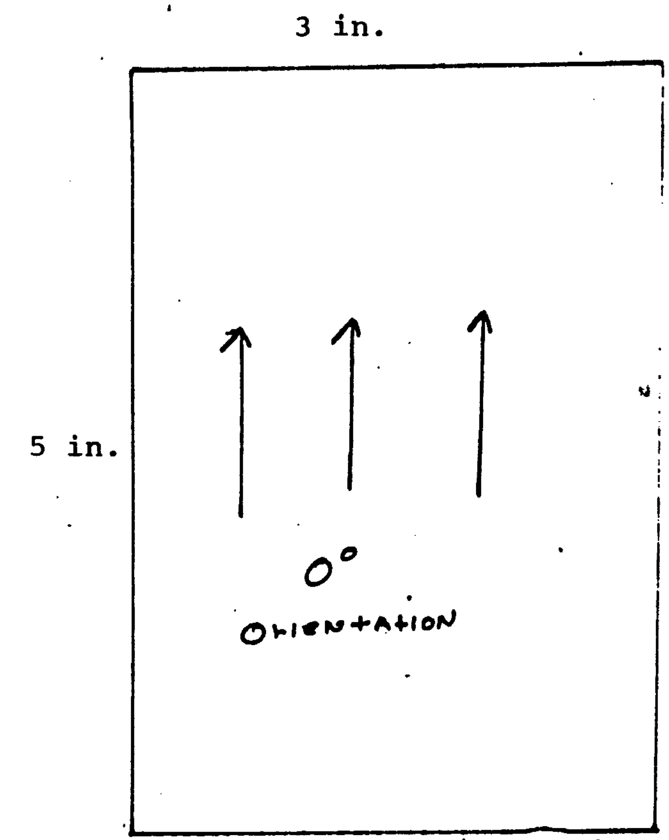


FIGURE A4

Front Spring Leaf No. 2



Cut Wear Pad with Orientation of Fiber

FIGURE A3

Wear Pad

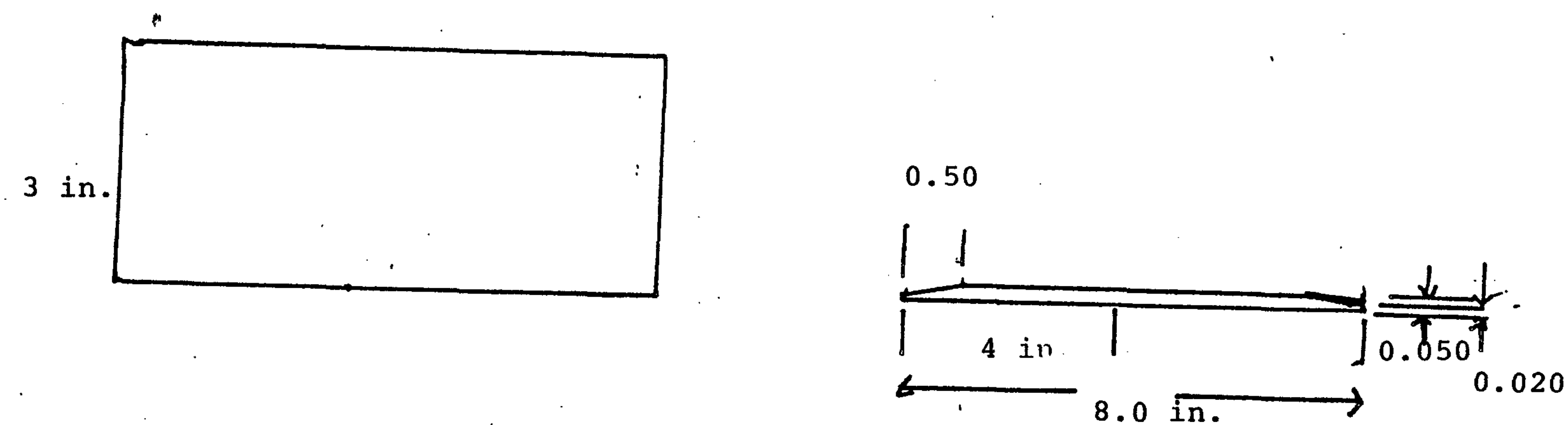


FIGURE A

G10 Board Pad

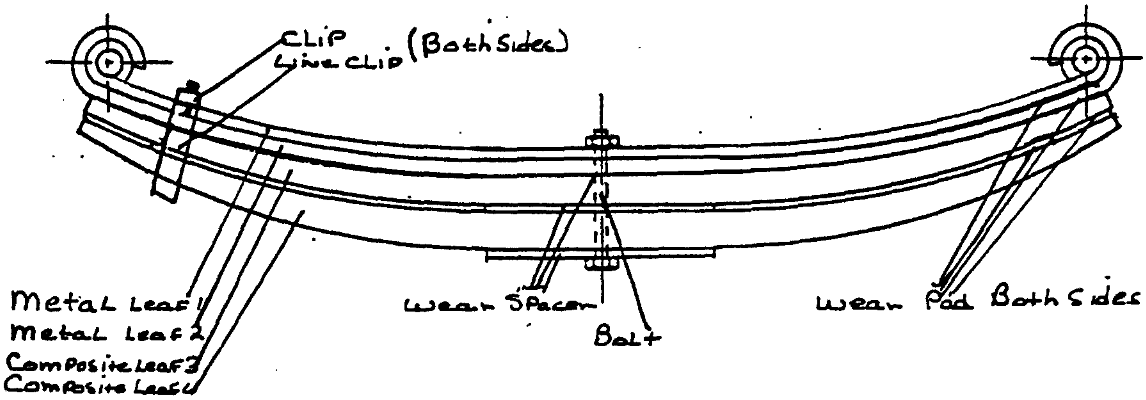


FIGURE A7

Front Leaf Spring Assembly

APPENDIX B

FABRICATION PROCESS SHEETS

FOR PROPELLER SHAFT COMPOSITE TUBE

MANUFACTURING PROCESS SHEET

Mfg/Job Order No. 396-004

Quantity 9

Start and Finish Schedule

S/N Effectivity

Part Number 650-392-005 Rev. B

Description Propeller Shaft, Tube Sub Assy

Issue Number

AACC 7NOV80		
Prepared By - Date	Approved By - Date	Q.A. Review - Date

MATERIAL REQUIREMENTS

SPECIFICATION	DESCRIPTION	AMOUNT PER PART
611000-003	Fiberite HyE-1048A1E	
612000-002	Narmco Metlbond 1133 adhesive	

SPECIAL INSTRUCTIONS

TOOLS AND EQUIPMENT

Mandrel T394-003A with rubber bladder per Process No. 223, issue 1.

MANUFACTURING PROCESS SHEET

Mfg/Job Order No. 396-004

Quantity 9

Start and Finish Schedule

S/N Effectivity

Part Number 650-392-005 B

Description Propeller Shaft Tube Sub Assy.

Issue Number

AAGC 6NOV80

Prepared By - Date

Approved By - Date

Q.A. Review - Date

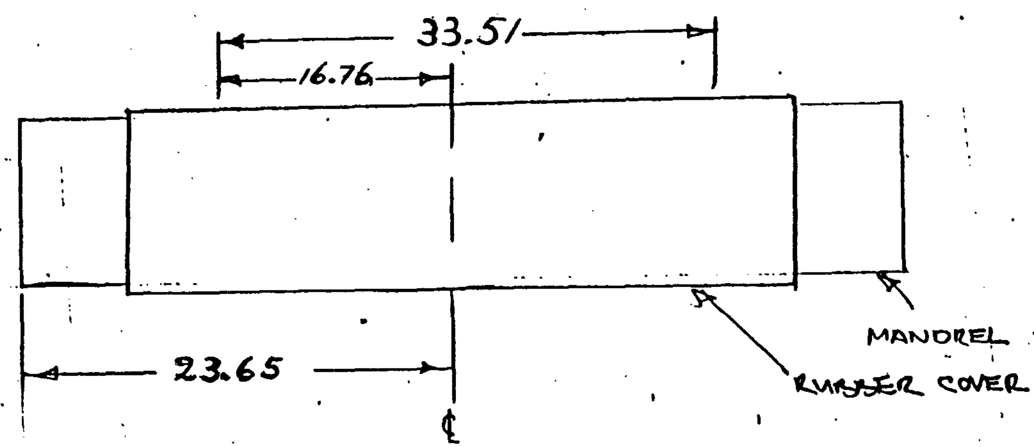
TOOL SURFACE (BLADDER)

PAT. NO.	PLY NO.	ORIENT-ATION	WIDTH (0°)	LENGTH (90°)	COMMENTS
1	1 2	+45 -45	33.51	10.0	
2	3	0	33.51	10.0	
3	4 5	+45 -45	33.51	10.0	COMPACT
4	6 7	+45 -45	33.63	10.3	
5	8	0	33.63	10.3	
6	9 10	+45 -45	33.63	10.3	COMPACT
7	11 12	+45 -45	33.75	10.3	
8	13	0	33.75	10.6	
9	14 15	+45 -45	33.21	10.6	COMPACT
10	16 17	+45 -45	32.67	10.6	
11	18 19	-45 +45	32.14	10.6	
12	20 21	-45 +45	31.60	10.9	COMPACT
13	22	0	31.33	10.9	
14	23 24	-45 +45	30.79	10.9	
15	25 26	-45 +45	30.25	10.9	
16	27	0	29.98	11.2	
17	28 29	-45 +45	29.45	11.2	COMPACT
18	30 31	-45 +45	28.91	11.2	
19	32	0	28.64	11.2	
20	33 34	-45 +45	28.10	11.2	COMPACT

MANUFACTURING PROCESS SHEET

Sheet 3 of 10
Part Number 650-392-005 B
Issue Number ______

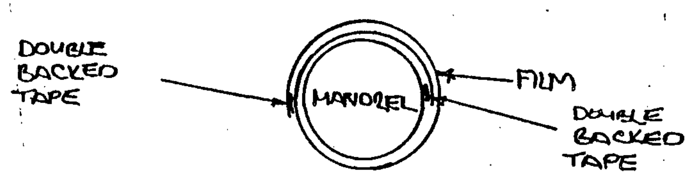
Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
5 - 663	Find center of mandrel within ±0.050 in. and mark on rubber bag. Mark the location of the layup edges on the rubber bag within ± 0.050 in. Use a ball point pen.				



NOTE: If the rubber bag is stored or a part is cured on the bag, it must be checked for leaks and repaired as required. See Operation Process Sheets on rubber bag fabrication, testing, and repair.

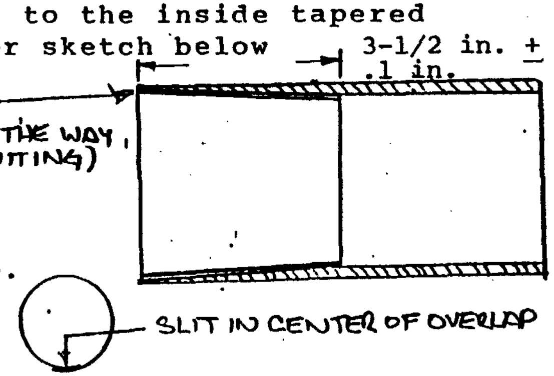
MANUFACTURING PROCESS SHEET

Sheet 4 of 10
Part Number 650-392-005 B
Issue Number ________

Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
10 - 663	Wrap rubber cover with 0.001 in. thick teflon film. Double backed tape should be used to secure film. The wrap must be 1½ times, not butt jointed. 				
15 - 663	Cut patterns per pattern cutting sheet (see sheet 2).				

MANUFACTURING PROCESS SHEET

Part Number 650-392-005 B
Issue Number ______

Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
20 - 663	Lay-up per stacking sequence shown on pattern cutting sheet (sh.2) Trim each pattern to wrap around the lay-up making a butt joint. No overlaps are permitted on butt joints, with the exception of the first pattern. Sometimes a slight overlap is required to get the first pattern to stay in place. A gap of 0.05 in. is allowable. Compact per pattern cutting sheet using nylon tape or tedlar. Each pattern must be centered in relation to the first ply on the mandrel within 0.050 in. Seams are to be advanced 1/2 in. around the layup for each pattern.				
25 - 663	Clean two end fittings with solvent to remove all oil, layout fluid etc. Sandblast inside of end fittings. Clean entire end fitting with Trichlorocthylene. Remove the paper backing and apply adhesive 612000-002 (Metlbond 1133) to the inside tapered sections of the steel end fittings per sketch below No overlap is allowed and no gap greater than 0.030 in. A good method is to cut the adhesive long in the circumferential direction, apply to the end fitting and trim in the center of the overlap. Remove all excess material. Leave green film in place.  				

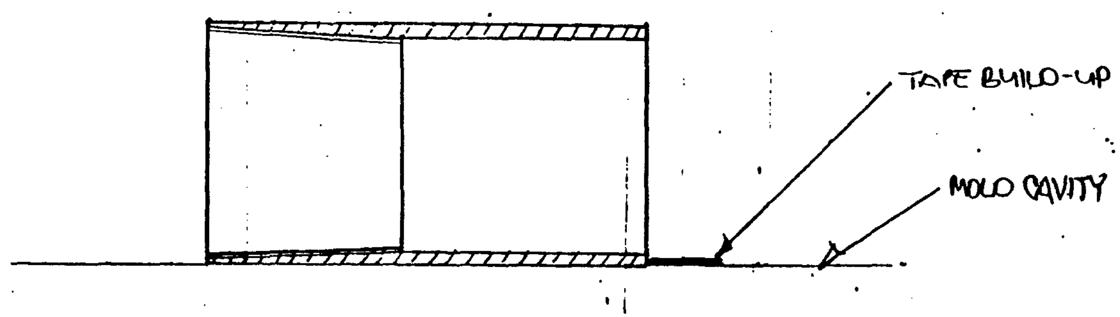
MANUFACTURING PROCESS SHEET

Part Number 650-392-005B
Issue Number ________

Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
26 - 663	Apply one coat of RAM 225 to outside of fittings. Do NOT get any of it on the inside.				
30 - 663	Check fit of end fittings on lay up.				
35 - 663	Clean mold cavity and faces with acetone. Apply two coats of RAM 225 release. Allow 5 minutes drying time between coats. Buff each coat lightly after drying. Be sure an excess buildup is not formed in mold corners.				
40 - 663	Center layup in one half of mold. Mark the location of the mold ends on tape affixed to the mandrel. Remove the teflon wrap back to these points. Measure distance from mold to edge of layup and record. Locate end fittings in mold half and mark outboard position on mold with pencil.				
45 - 663	Close mold and clamp. Be sure indicator marks on mold are aligned properly.				

MANUFACTURING PROCESS SHEET

Sheet 7 of 10
Part Number 650-392-005B
Issue Number ______

Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
46 - 663	Remove mandrel ends. Tape edges of mandrel tube under rubber to prevent the edges from cutting the rubber.				
50 - 663	Remove green film from one sleeve and insert sleeve into mold until it sets against stops, and pencil mark (operation 40) is visible. Build up a few layers of 900004-001 (green mylar tape) on tool to limit sleeve movement. Pieces of tape about 1/2 inch square will do.  				
55 - 663	Insert layup into the mold from the end without a sleeve in place. Use the marks made in operation 40 to center the layup in the mold. BE SURE LAYUP IS CENTERED IN MOLD AND ON MANDREL.				

MANUFACTURING PROCESS SHEET

Sheet 8 of 10
Part Number 650-392-005B
Issue Number ________

Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
60 – 663	Remove green film from remaining sleeve and insert sleeve into mold until pencil mark is visible. Make a stop with tape as in operation 50. BE SURE LAYUP IS CENETERED ON MANDREL.				
65 – 663	Insert a thermocouple wire into each end of the part, between the teflon covered rubber bladder and the steel sleeve. Use the measurements shown in Operation 40 to keep the wire away from the composite layup. DO NOT GET THE WIRE BETWEEN THE LAYUP AND THE SLEEVE. Cover the wire ends with mylar tape to prevent bag puncture.				
70 – 663	Put aluminum rings in place on mold and fold rubber back over rings. Trim rubber a little if it is too long. The thermocouple wires run in grooves under the rings.				

MANUFACTURING PROCESS SHEET

Sheet 9 of 10
Part Number 650-392-005B
Issue Number ________

Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
75 – 663	Clamp end plates in place. Tighten bolts evenly. Only enough torque is required to prevent the leakage of air. Apply 30 PSI. If leaks are audibly present tighten bolts until leakage stops. Apply 85 PSI and again check for leaks. Tighten bolts if necessary.				
80 – 663	Place mold in oven. Apply 85 PSI. Loosen a couple of clamp bolts slightly until air leakage is heard to be sure pressure is getting to the part. Retighten bolts. Attach thermocouple wires to recorder and start recorder. Heat oven to 300°F. When recorder charts shows 250°F ±5°F, turn oven temperature to 250°F. Cure part at 250°F ± 5°F for a minimum of 2 hours and a maximum of 3 hours. Cool under pressure to 175 °F. Release pressure.				
85 – 663	Remove clamp bolts in end plates. Remove thermocouple wires. Remove rubber covered mandrel. Unclamp mold halves. Remove upper mold half. Remove part. Submit to Q.C. for inspection.				

MANUFACTURING PROCESS SHEET

Sheet 10 of 10
Part Number 650-392-005B
Issue Number ______

Oper No Mfg No Dept No	OPERATION DESCRIPTION Tooling, Fixture, Gauge, etc.	Set-Up Run/Pc Pcs/Hr	Sched. Start/ Finish	Spvsr Initl/ Oprtr Quan Fin	QC Initl
90 - 668	Inspect part.				
100 - 663	Release acceptable part to stores.				

OPERATION PROCESS SHEET

DWG NO. 650-392-002

PART NO.

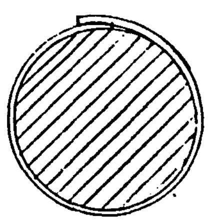
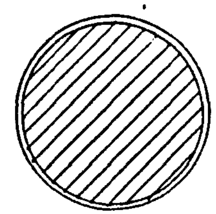
REV.A ISSUE No. 1 PROCESS No. 0223

PREPARED BY Grant Robison DATE 2-25-80

JOB TARADCOM JOB

DRIVE Shaft ~~Fabrication~~ RUBBER BAG

PART DESCRIPTION

Oper No.	Dept	Operation Description Sheet 1 of 2	Stamp	Date & Time	Remarks
5	663	Disassemble mandrel and clean all parts with acetone. Reassemble mandrel.			
10	663	Release the mandrel with a mixture of liquid soap and water, about 60 percent water, 40 percent soap. Allow to dry thoroughly.			
15	663	Form silicone rubber bag over entire mandrel with 60-A-00, (Mosites 1453D, .080" thick). Make seam by overlapping as shown below. Knead and smooth the rubber in the area of the seam with a spatula shaped tool with a rounded blade about 1/2 in. wide. A tool made from a saw blade or metal strapping can be used. Work the rubber in such a manner so to knead the two cut edges together. Smooth the rubber in the area of the seam to approximately the same thickness as the surrounding rubber.  RUBBER OVERLAPPED  RUBBER AFTER KNEADING AND SMOOTHING			
20	663	WRAP THE RUBBER CAREFULLY WITH A LAYER OF TEFLON FILM. TAPE IN POSITION WITH MYLAR TAPE. Wrap the rubber carefully with 60-B-00(tedlar film 3/4 in. wide) or 61-B-02(tedlar film 2 in. wide). Wrap lightly. The purpose of the film is to prevent the rubber from sagging at elevated temperatures.			
25	663	Cure the rubber at 300°F for 30 minutes. Set the mandrel in the oven so that no weight will rest on the rubber. Setting the mandrel on one end with nut on the other end leaning against a support is one way to accomplish this.			

OPERATION PROCESS SHEET

DWG NO. 650-392-002

JOB TARADCOM JOB NO.

PART NO.

PREPARED BY Grant Robison DATE 2-25-80

PART DESCRIPTION Shaft Fabrication

Oper No.	Dept	Operation Description Sheet 2 of 2	Stamp	Date & Time	Remarks
30	663	When the part is cool enough to work with, remove the tedlar wrapping. Clamp the ends of the bag to the mandrel with hose clamps. Use a piece of scrap rubber or a layer of 61-E-00 (nylon tape, 1 in.) wide) under each hose clamp to protect the rubber from being cut by the hose clamps.			
35	663	Screw a male air coupling into the mandrel and apply about 5 PSI. Make sure the bag is not stuck to the mandrel except at the clamped areas. If it is, apply a little more air pressure. Air will not flow in stuck areas so you cannot get a check for leaks there.			
40	663	Make a solution of liquid soap and water (60% water and 40% soap). Brush the solution all over the rubber bag. The presence of air bubbles indicates air leakage.			
45	663	If leaks OR THIN SPOTS are present, mark their location. Wipe the bag dry and clean a large area around each leak or thin spot with acetone. The purpose of cleaning with acetone is to remove the soap solution from the bag. Soap is a release agent for silicone rubber. Upbraid the surface of the bag with sandpaper until the surface is visibly roughened. Apply a patch of uncured silicone rubber to the leak or thin spot. The patch should be larger than the leak or thin spot. Work the rubber with a spatula type tool to achieve adhesion of the patch to the bag and to feather the edges of the patch.			
50	663	Cure the patch and postcure the bag at 300°F for 2 hours.			
55	663	Recheck the bag for leaks and repair as required, as in Operations 30, 35, 40, 45 and 50.			
60	663	Proceed immediately to layup. If the bag is stored or a part is cured on the bag, it must be rechecked for leaks and repaired as required.			

APPENDIX C

ULTRASONIC C-SCAN RESULTS

C-SCAN FOR LEAVES

TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-22-80

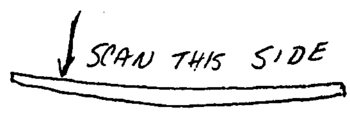
SPRING No. -3 SN 2 * 1 XDCR TYPE 0.50 PANAMETERS XDCR FREQ. 2.25 MHz.

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 10-20 dB

AVG. PEAK OUTPUT 0.2 V GATE DELAY ______ GATE WIDTH ______

SCAN SPEED 6 IPS INDEX INCR. 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: NO SIGNIFICANT FLAW INDICATIONS

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TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-23-80

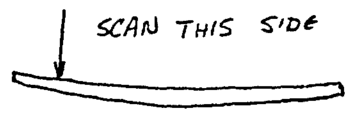
SPRING No. -3 SN 2 #2 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 10Db - 18dB

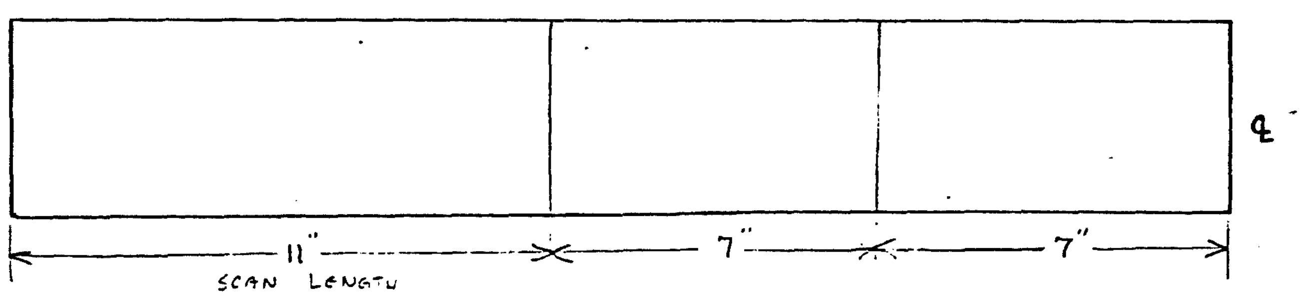
AVG. PEAK OUTPUT 0. GATE DELAY 10-20 μs GATE WIDTH 7 μs

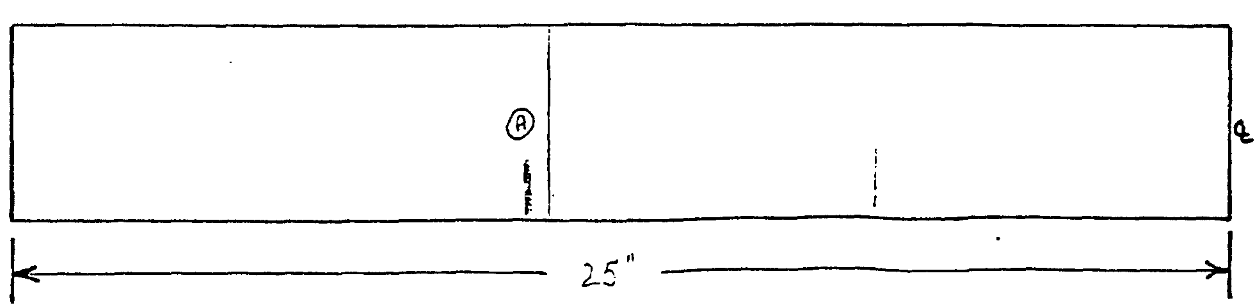
SCAN SPEED 6.0 IPS INDEX INCR 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: (A) LEVEL 2 AREA 2 2/3 t





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-23-80

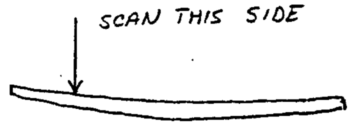
SPRING No. -3 SN2 #3 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHZ

REP. RATE 5K ENERGY 2 GAIN 40 dB ATTEN. 10-20 dB

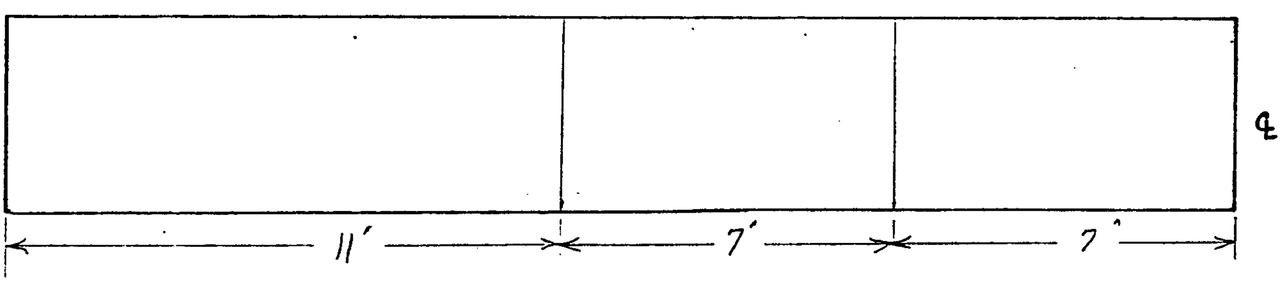
AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 μS GATE WIDTH 7 μS

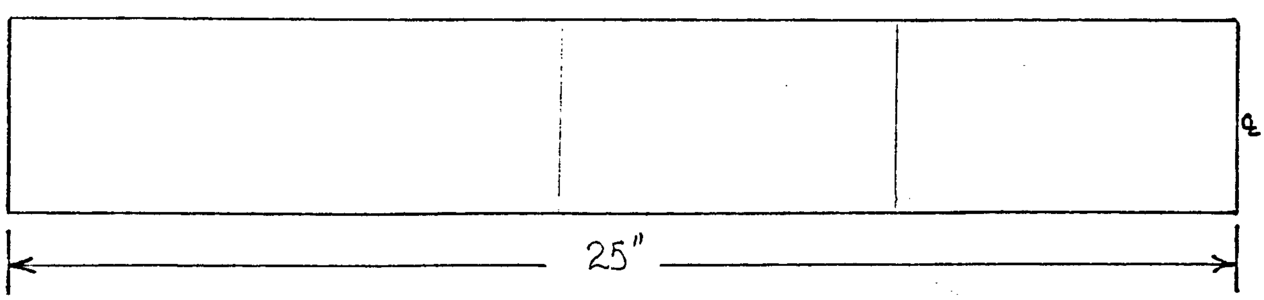
SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: NO SIGNIFICANT FLAW INDICATIONS





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-23-80

SPRING No. -3 SN 2 #4 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

REP. RATE 5 K ENERGY 2 GAIN 40 dB ATTEN. 10 - 18 dB

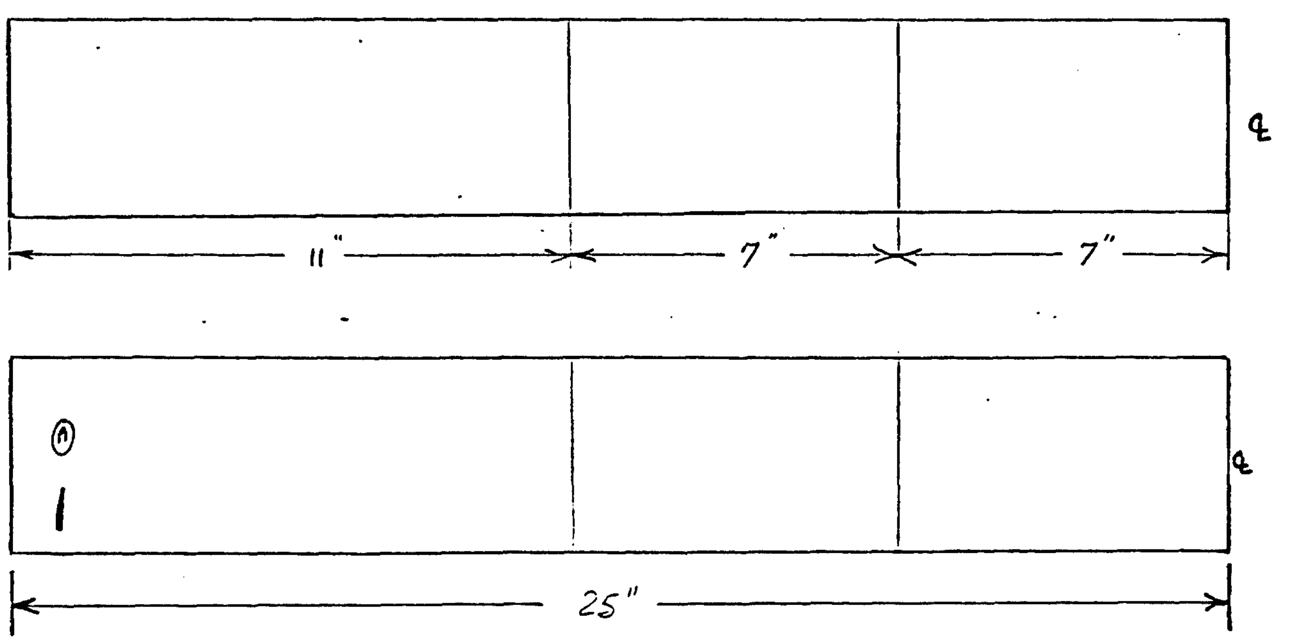
AVG. PEAK OUTPUT 0.2V GATE DELAY 10-20 NS GATE WIDTH 7NS

SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.

SCAN THIS SIDE

RESULTS: (A) LEVEL 2 AREA 1 1/2 t



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-20-80

SPRING No. -3 SN2 #5 XDCR TYPE 0.75" PANAMETRICS XDCR FREQ. 5.0 Mhz

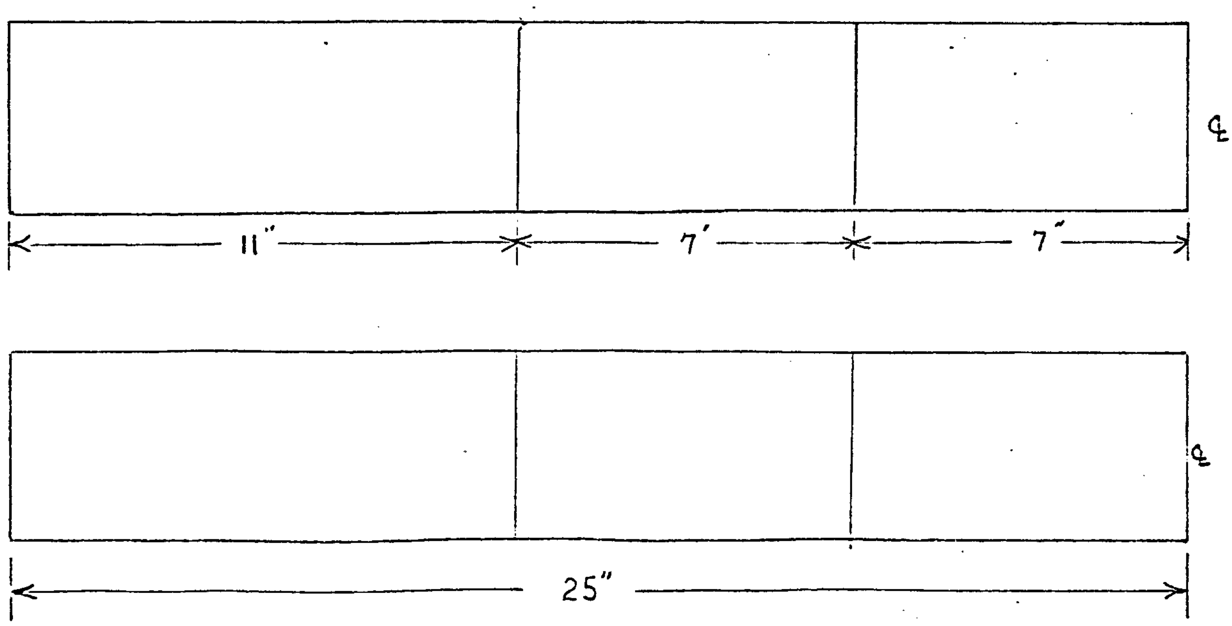
REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 20 dB

AVG. PEAK OUTPUT 0.2v GATE DELAY 10-20 μs GATE WIDTH 7 μs

SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. <4 SQ IN.

RESULTS: NO SIGNIFICANT FLAW INDICATIONS



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10/24/80

SPRING No. -3 SN 2 # 6 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz.

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 10 - 18 dB

AVG. PEAK OUTPUT 0.2V GATE DELAY 10-20 μS GATE WIDTH 7 μS

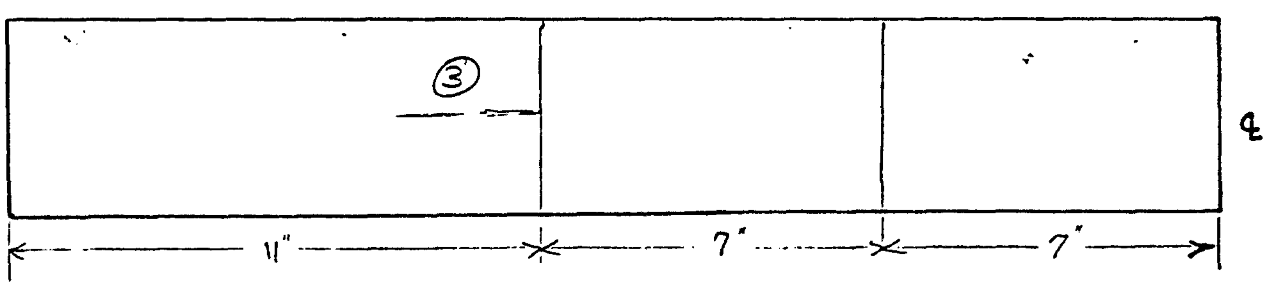
SCAN SPEED 6 IPS INDEX INCR. 0.025 in. INDEX DIRECTION TRANS

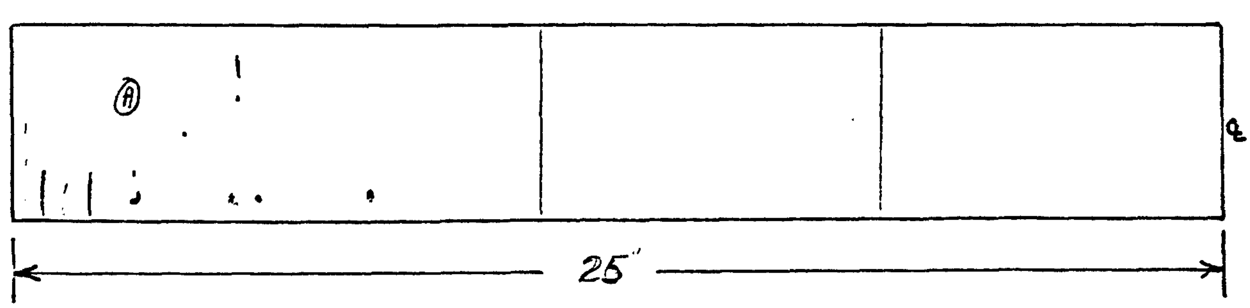
INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.

SCAN THIS SIDE

RESULTS: (A) LEVEL 2 AREA 2 - 1/2 t - SMALL AND SCATTERED PROBABLY PLY ENDS

(B) LEVEL 2 AREA 2 1/3 t





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-21-80

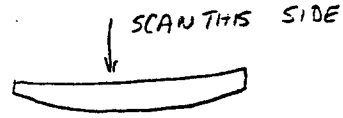
SPRING No. -4 SN 1 # 1   XDCR TYPE 0.75" PANAMETRICS   XDCR FREQ. 5.0 mhz

REP. RATE 5K   ENERGY 2   GAIN 40 dB   ATTEN. 20 dB ENDS 12 dB MIDDLE

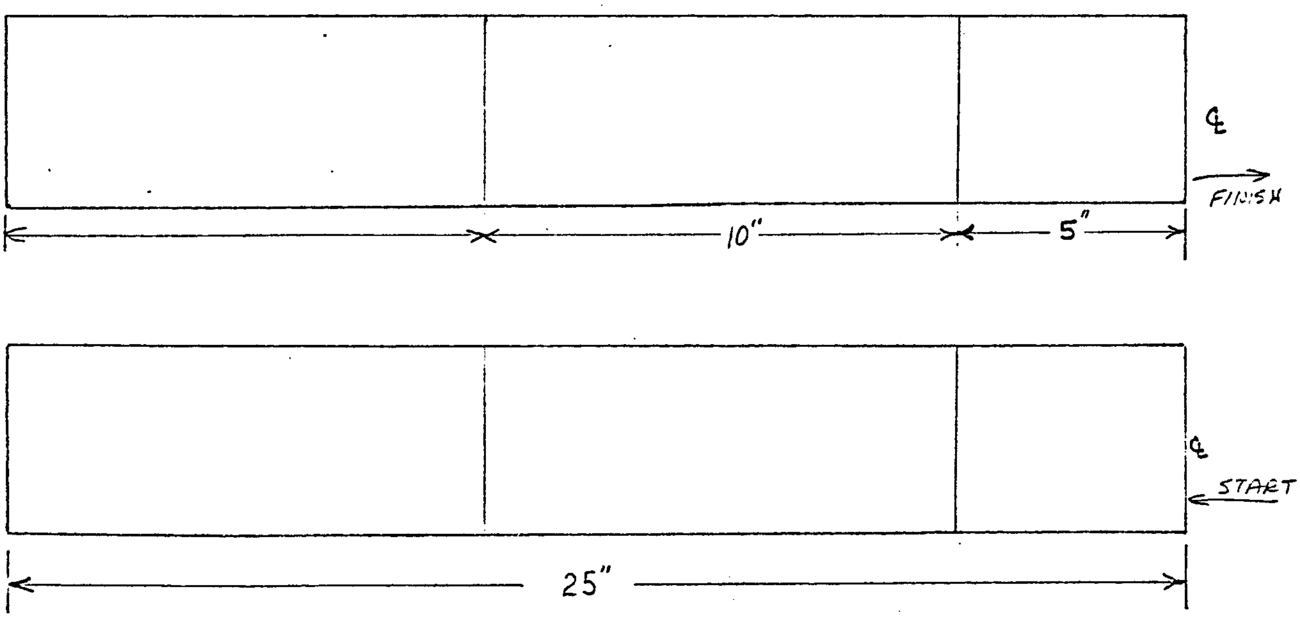
AVG. PEAK OUTPUT 0.2 V   GATE DELAY 10-20 NS   GATE WIDTH 7 NS

SCAN SPEED 6 IPS   INDEX INCR 0.025 in.   INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: NO SIGNIFICANT FLAW INDICATIONS



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-21-80

SPRING NO. -4 SN 1 #2 XDCR TYPE 0.75" PANAMETRICS XDCR FREQ. 5.0 MHz

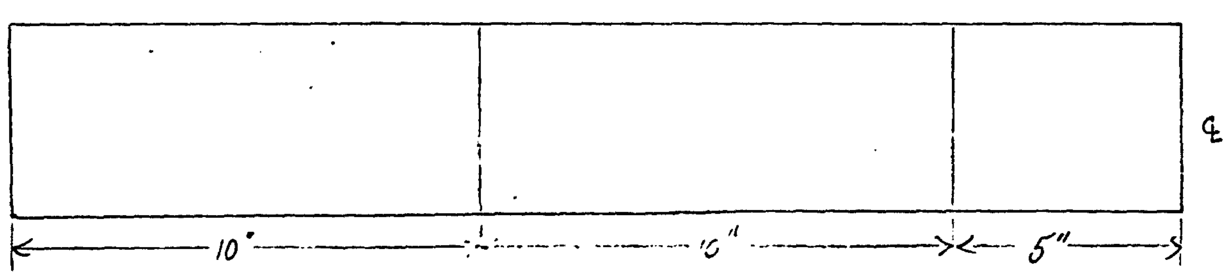
REP. RATE 5K ENERGY 2 GAIN 40 dB ATTEN. 20dB ENDS 12 dB- MIDDLE

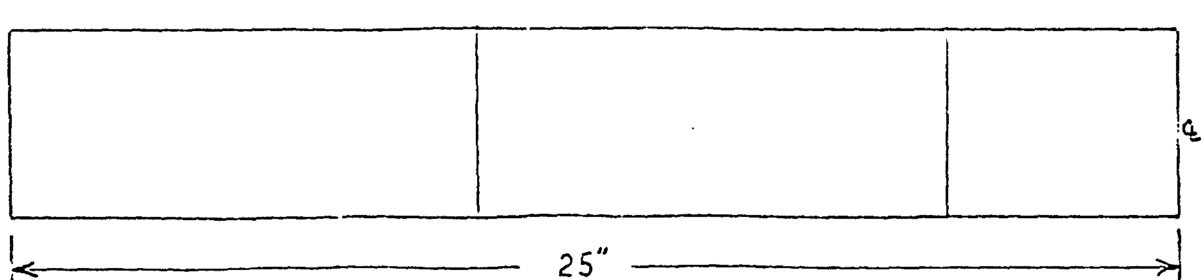
AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 NS GATE WIDTH 7 NS

SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.

RESULTS: NO SIGNIFICANT FLAW INDICATIONS





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-21-80

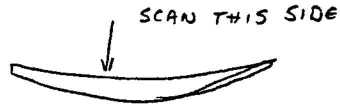
SPRING No. -4 SN1 #3 XDCR TYPE 0.75" PANAMETRICS XDCR FREQ. 5.0 Mhz

REP. RATE 5K ENERGY 2 GAIN 40. dB ATTEN. 10-20 dB

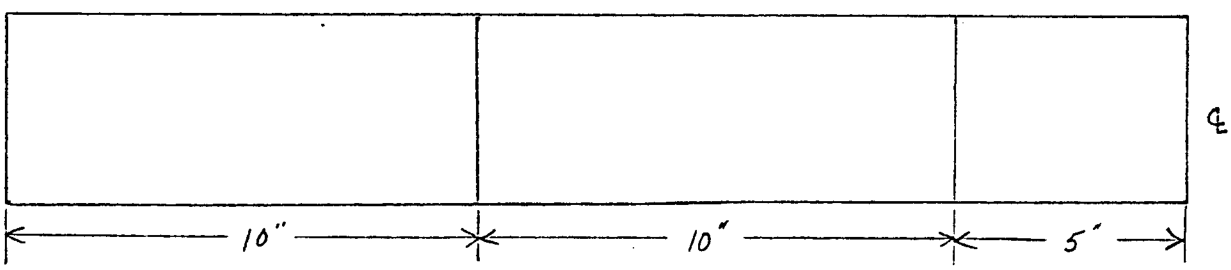
AVG. PEAK OUTPUT 0.2V GATE DELAY 10-20 NS GATE WIDTH 7 NS

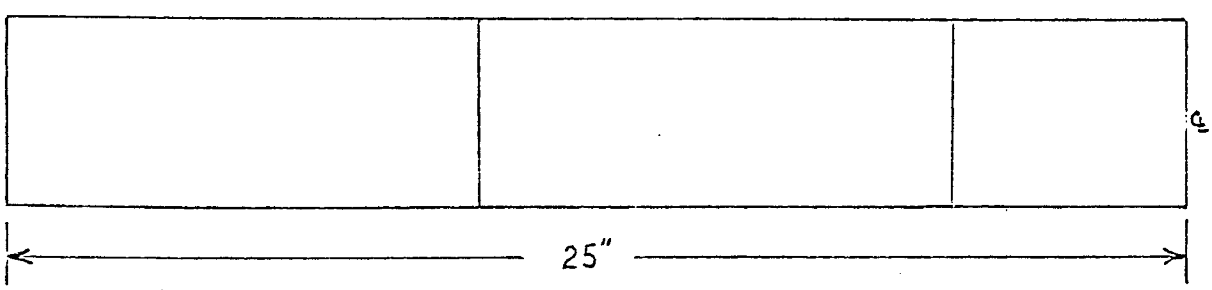
SCAN SPEED 6 I.P.S. INDEX INCR 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: NO SIGNIFICANT FLAW INDICATIONS





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-21-80

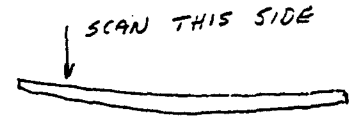
SPRING No. -4 SN 1 # 4 XDCR TYPE 0.75" PANAMETRICS XDCR FREQ. 5.0 MHz

REP. RATE 5K ENERGY 2 GAIN 40 dB ATTEN. 12-20 dB

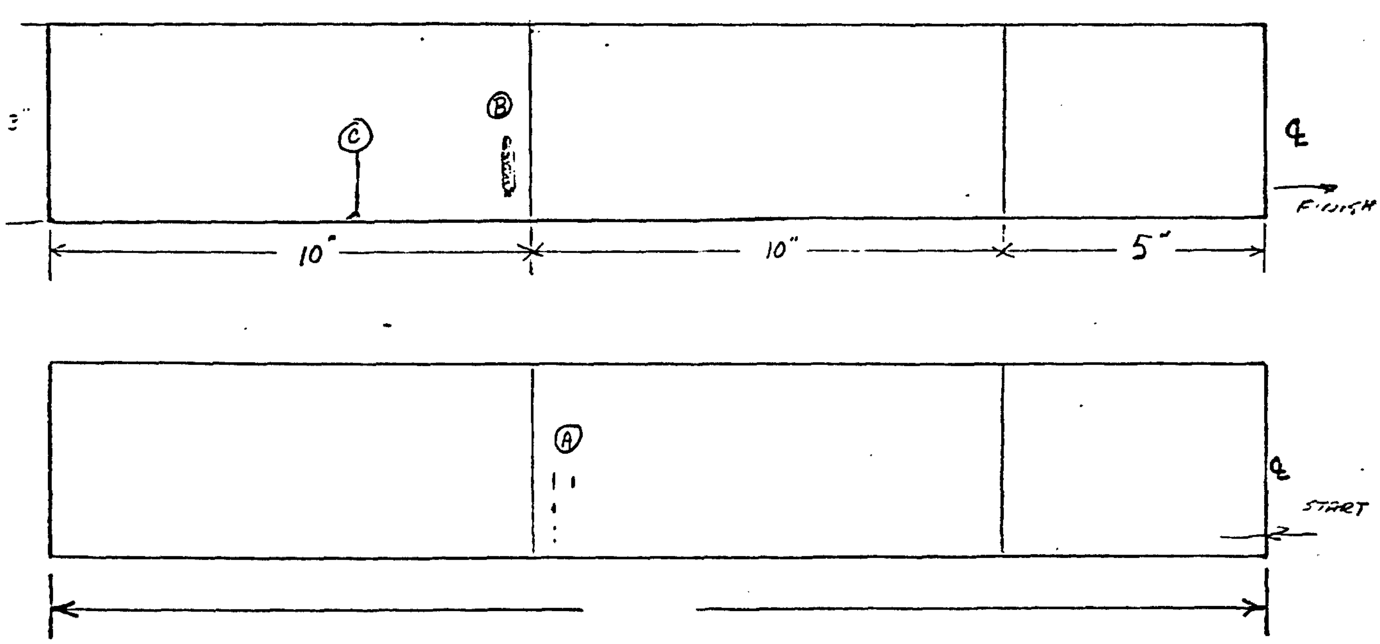
AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 NS GATE WIDTH 7 NS

SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. <4 SQ IN.



RESULTS: (A) LEVEL 2 AREA 1 2/3 t
(B) LEVEL 2 AREA 2 1/2 t
(C) LEVEL 2 AREA 2 1/2 t



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-22-80

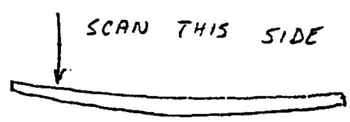
SPRING No. -4 SN1 #5 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHZ

REP. RATE 5K ENERGY 2 GAIN 40 dB ATTEN. 10-18 dB

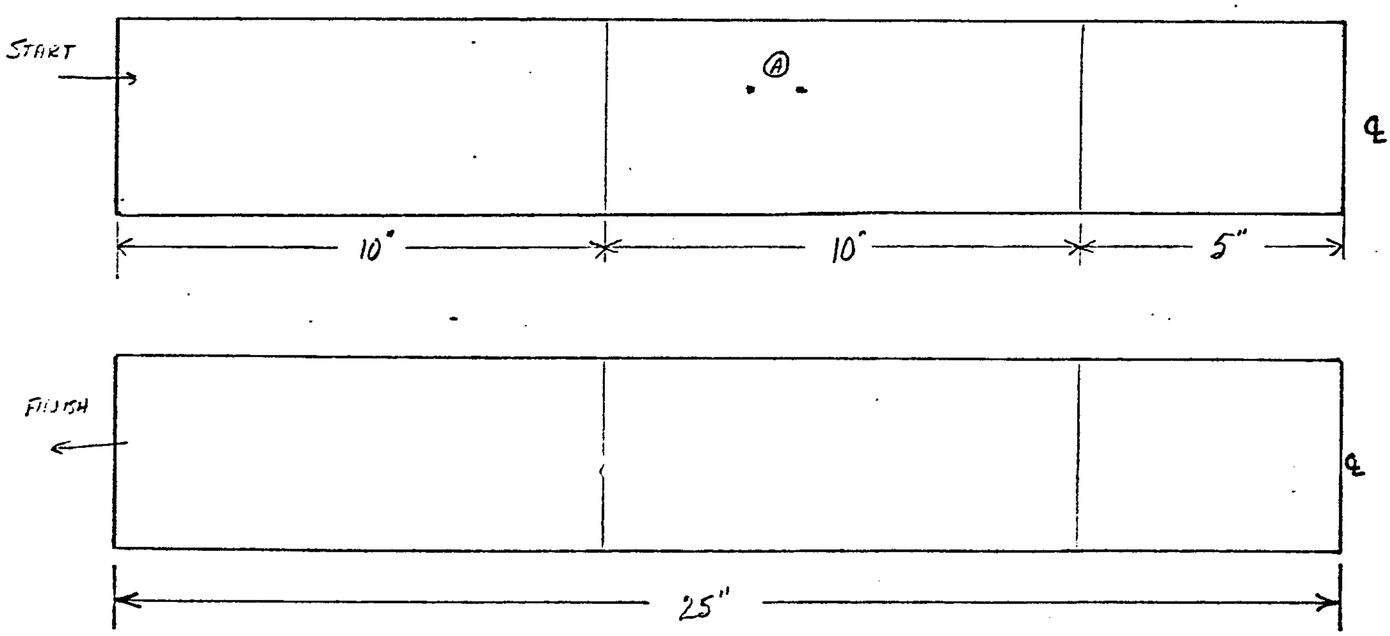
AVG. PEAK OUTPUT 0.2V GATE DELAY 10-20 NS GATE WIDTH 7 NS

SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. <4 SQ IN.



RESULTS: (A) LEVEL 2 AREA 1 VERY LOW LEVEL INDICATIONS NEAR BACK SURFACE



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-22-80

SPRING No. -4 SN 1 #6 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 10-18 dB

AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 NS GATE WIDTH 7 NS

SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION TRANS

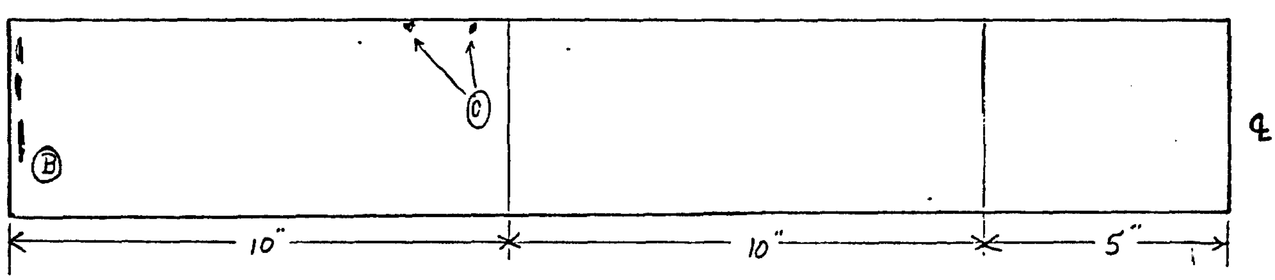
INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. <4 SQ. IN.

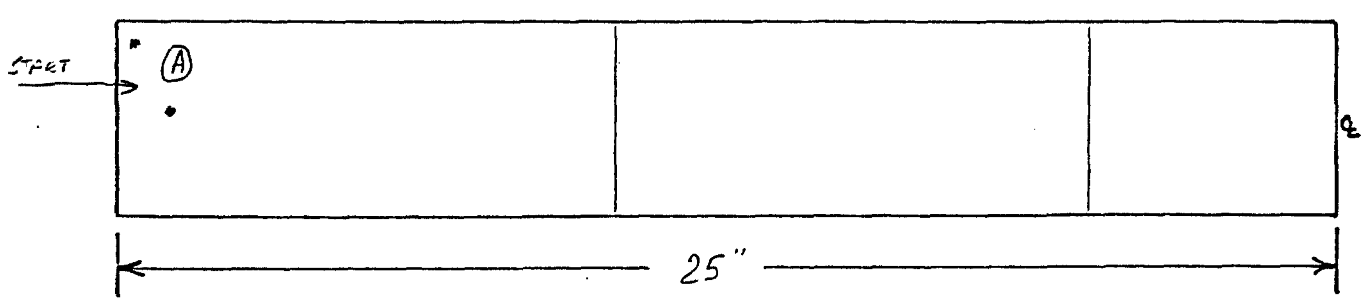
SCAN THIS SIDE

RESULTS: (A) LEVEL 2 AREA 1 2 SMALL INDICATIONS 1/2 t

(B) LEVEL 3 AREA 2 1/2 t

(C) LEVEL 2 AREA 2 1/3 t





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-22-80

SPRING No. -4 SN 1 #7 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

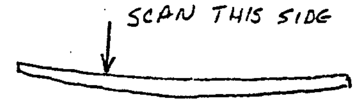
REP. RATE 5k ENERGY 2 GAIN 40dB ATTEN. 10-20 dB

AVG. PEAK OUTPUT 0.2V GATE DELAY 10-20 NS GATE WIDTH 7NS

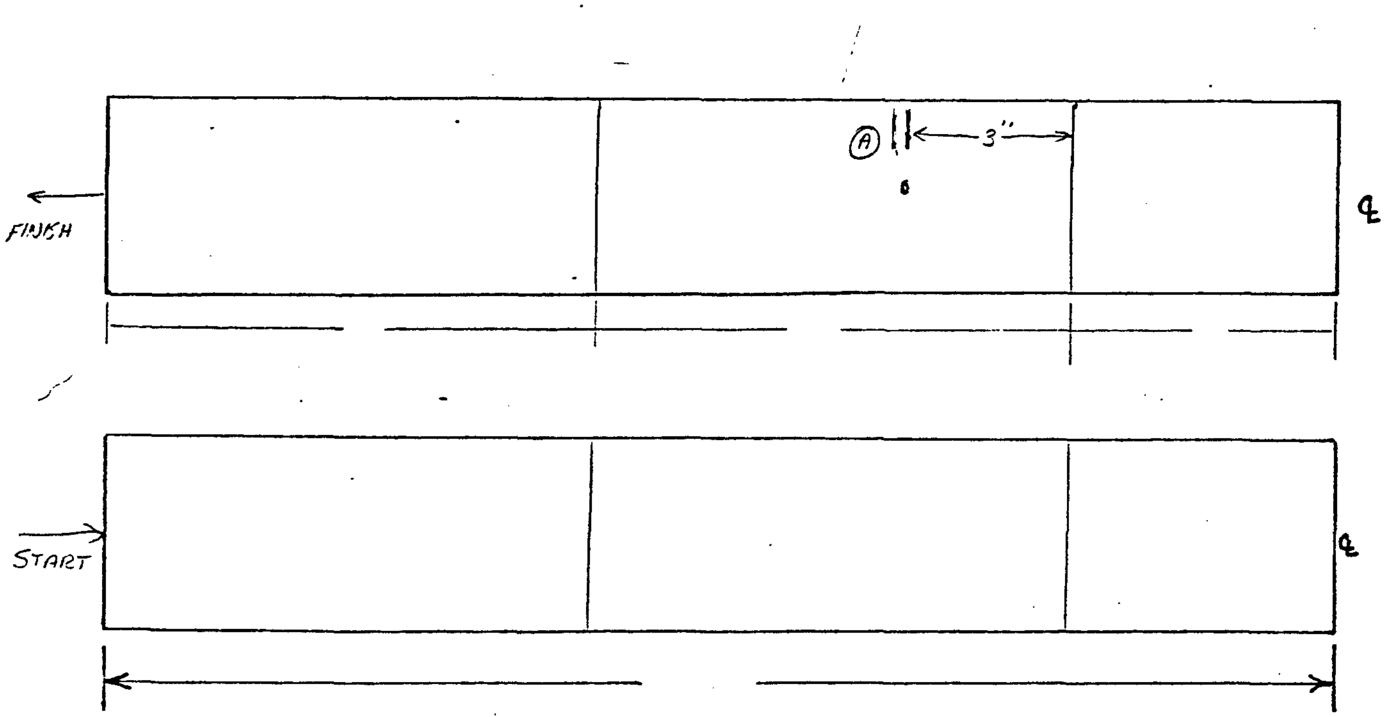
SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.

SCAN THIS SIDE



RESULTS: (A) LEVEL 2 AREA 2 NEAR BACK SURFACE REFLECTION



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-17-80

SPRING No. R-3 SN 2 #1 XDCR TYPE 0.75" PANAMETRICS XDCR FREQ. 5 Mhz

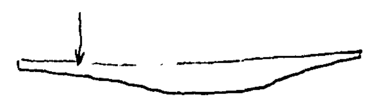
REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 18 dB

AVG. PEAK OUTPUT 0.2 V GATE DELAY 10.15 NS GATE WIDTH 5 NS

SCAN SPEED 7 IPS INDEX INCR 0.025 in. INDEX DIRECTION TRANS

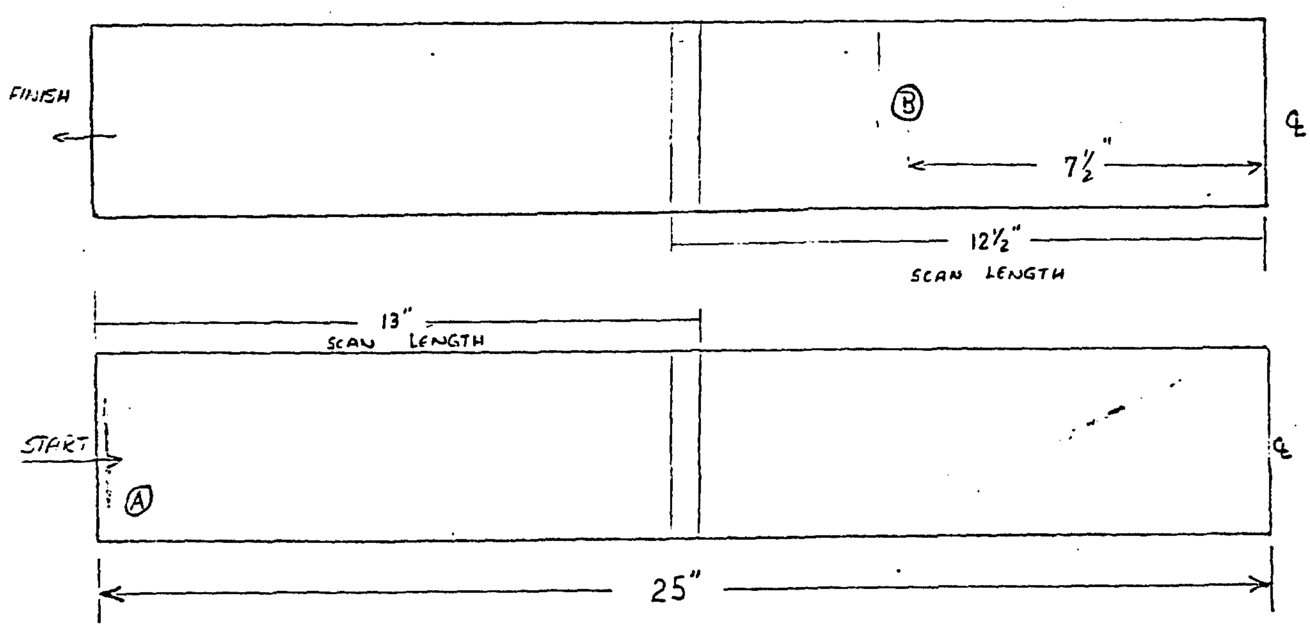
INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ IN.

SCAN THIS SIDE



RESULTS: (A) LOSS OF BACK REFLECTION AT END OF SPRING - NO INDICATION OF FLAW

(B) RESIN RICH AREAS AT PLY ENDS. AREA 2 LEVEL 2



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-17-80

SPRING No. R-3 SN 2 #2 XDCR TYPE 0.75" PANAMETRICS XDCR FREQ. 5.0 mhz

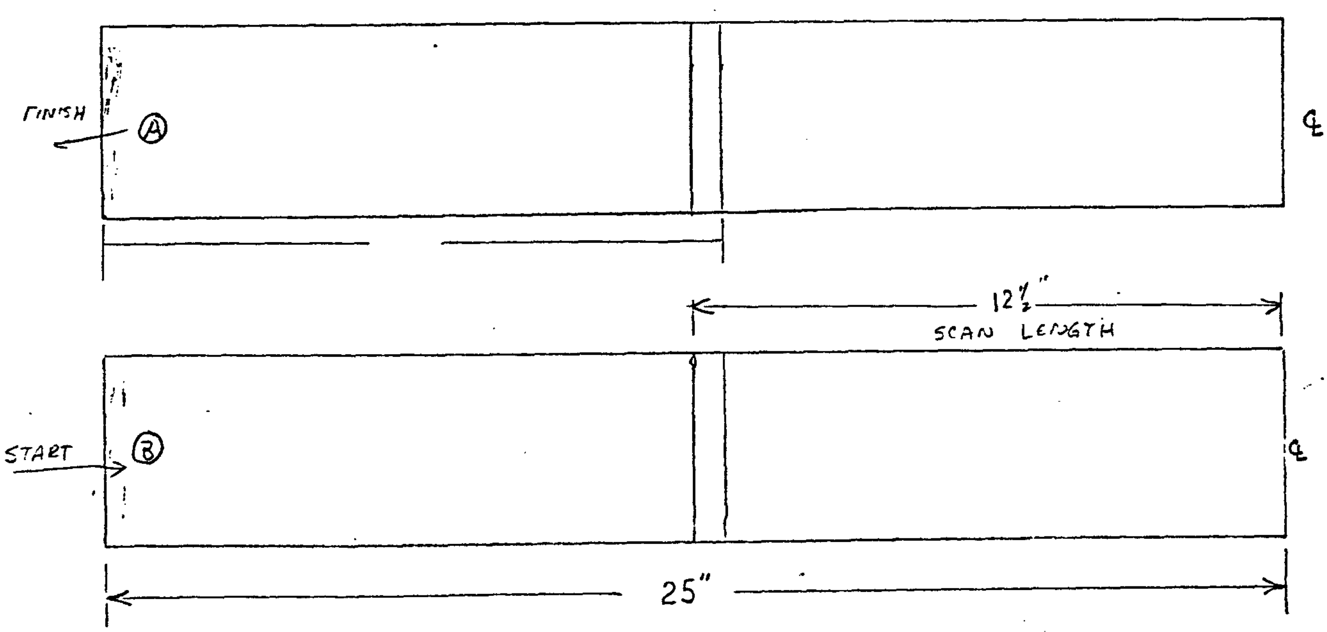
REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 18 dB

AVG. PEAK OUTPUT +0.2 V GATE DELAY 10-15 NS GATE WIDTH 5 NS

SCAN SPEED 6 IPS INDEX INCR 0 .025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.

RESULTS: (A) INDICATIONS CAUSED BY SIGNAL LOSS AT CURVE ON END OF SPRING
(B) SEE (A)



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-16-80

SPRING No. R-3 SN2 #3 XDCR TYPE 0.75" PANAMETRICS XDCR FREQ. 5.0 MHz

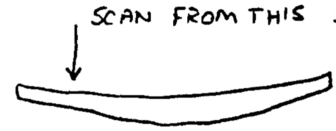
REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 20dB

AVG. PEAK OUTPUT 0.2 v GATE DELAY 20-25 NS GATE WIDTH ≈5NS

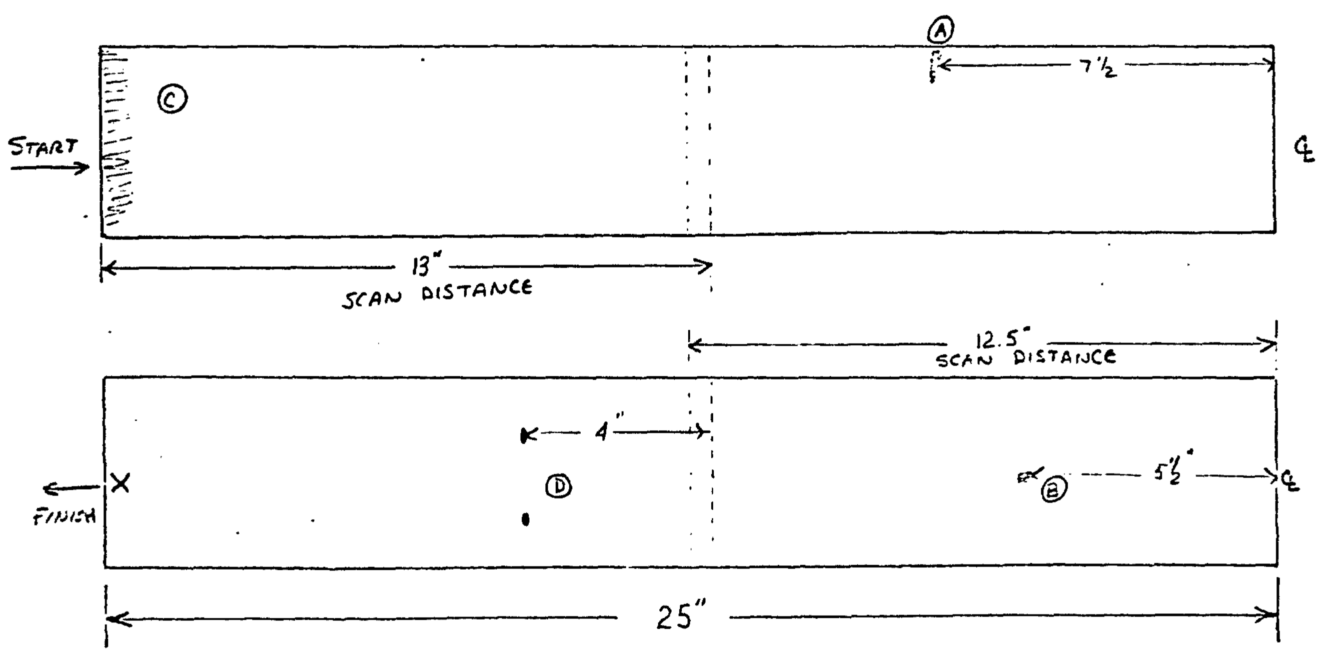
SCAN SPEED 7 IPS INDEX INCR 0.010 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.

SCAN FROM THIS SIDE



RESULTS:
(A) AREA 2 INDICATION WITH LEVEL 2 SIGNAL (RESIN?)
(B) SAME AS (A)
(C) LOSS OF SIGNAL CAUSED BY CURVATURE ON END OF SPRING.
(D) TWO INDICATIONS, EACH AREA 1 AND LEVEL 2. RESIN RICH AREA AT PLY ENDS IS PROBABLE CAUSE.



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-18-80

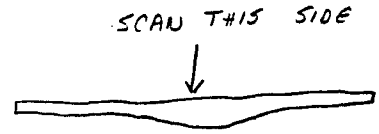
SPRING No. R-3 SN2 #4 XDCR TYPE 0.75" PANAMETRICS XDCR FREQ. 5.0 mhz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 18 dB

AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-15 NS GATE WIDTH 5.0 NS

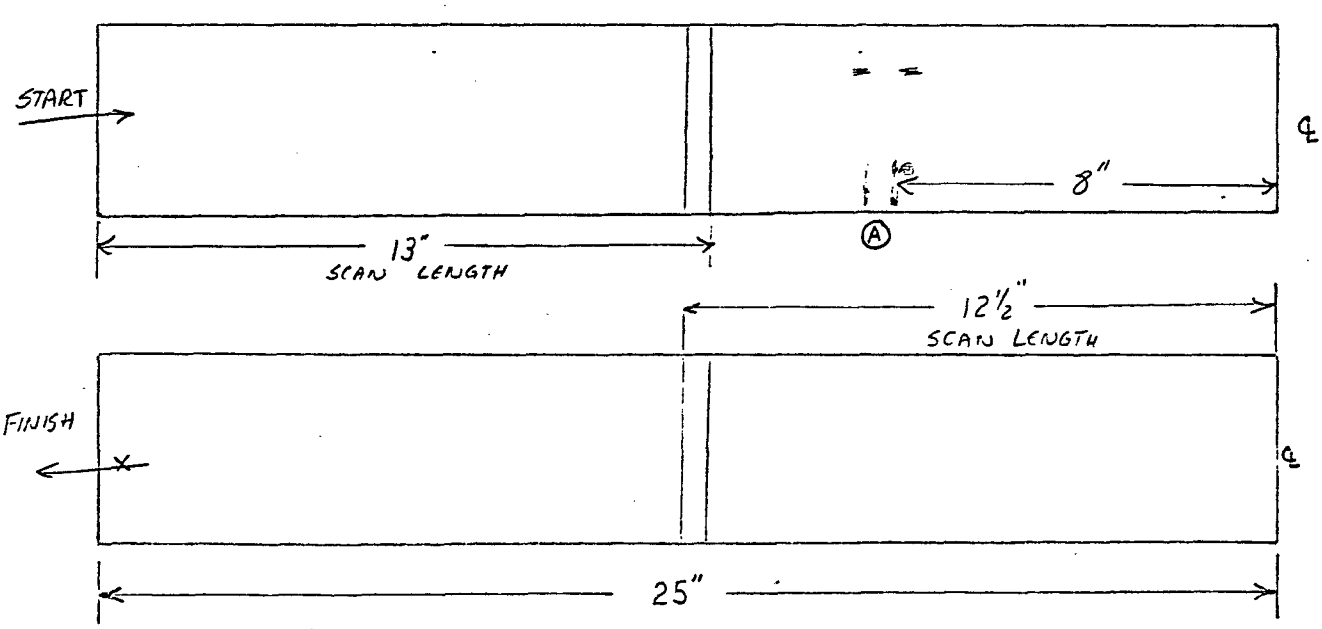
SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: (A) LEVEL 2 INDICATION WITH AREA 3 1/2 t FROM SCANNED SURFACE

(B) LEVEL 2 INDICATION WITH AREA 2 3/4 t FROM SURFACE



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-17-80

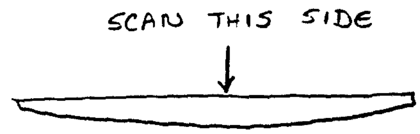
SPRING No. R-3 SN 2 #5 XDCR TYPE 0.75" PANAMETRICS XDCR FREQ. 5.0 mhz

REP. RATE 5K ENERGY 2 GAIN 40 dB ATTEN. 18 dB

AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-15 NS GATE WIDTH 5NS

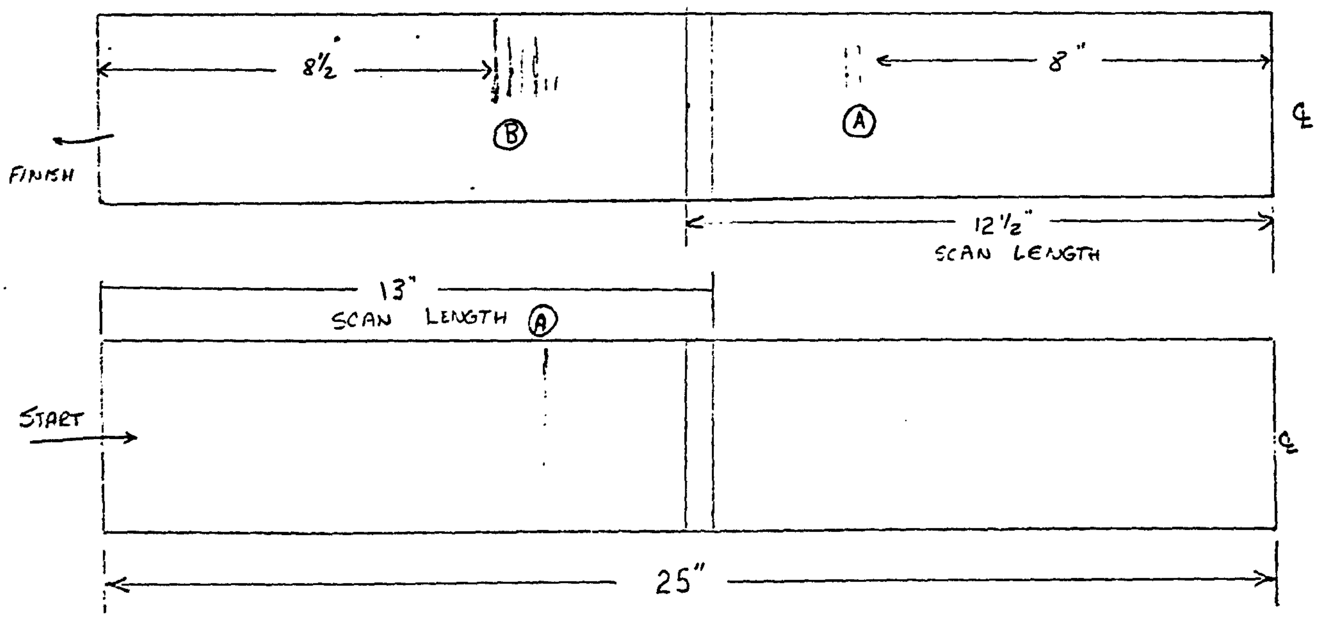
SCAN SPEED 7 INDEX INCR 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: (A) AREA 2 LEVEL 2 INDICATION - RESIN RICH PLY ENDS

(B) SAME AS (A) EXCEPT AREA 3



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-17-80

SPRING No. R-3 SN 2 #6 XDCR TYPE 0.75" PANAMETRICS XDCR FREQ. 5.0 Mhz

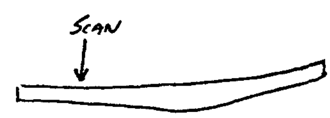
REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 20 dB

AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-15 NS GATE WIDTH 5 NS

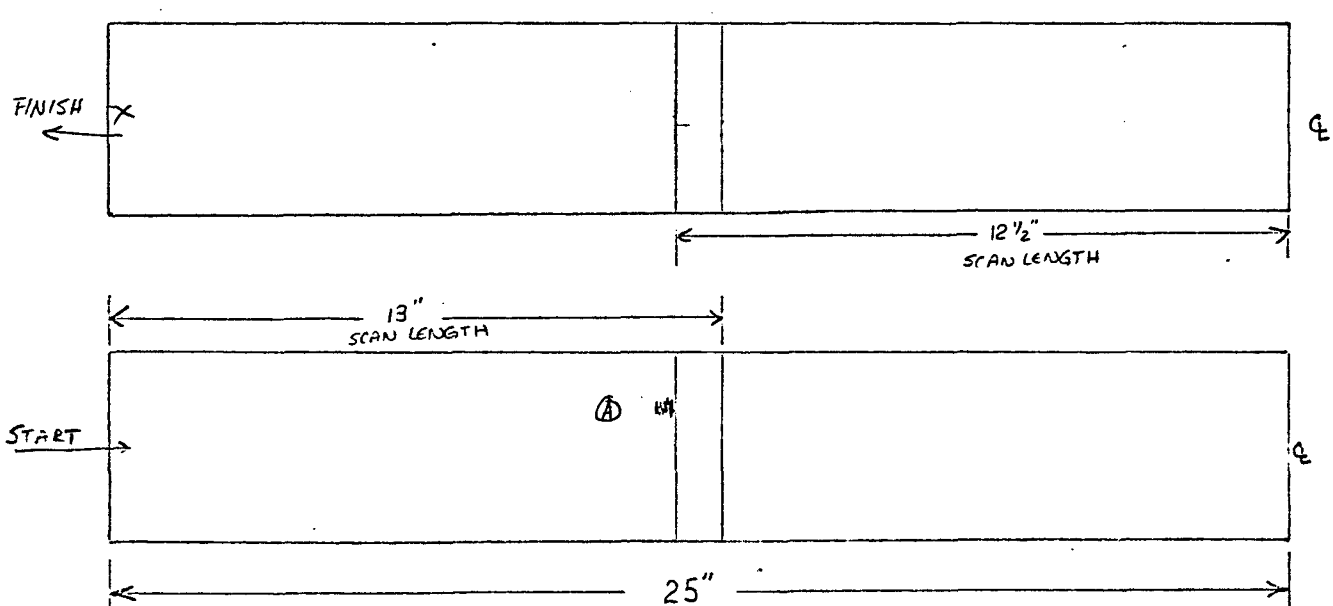
SCAN SPEED 7 IPS INDEX INCR 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.

SPRING SCANNED FROM THIS SIDE:



RESULTS: Ⓐ AREA 2 INDICATION WITH LEVEL 3 SIGNAL. APPROX. 2/3 t FROM SCANNED SURFACE



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-20-80

SPRING No. R4 SN 1 #1 XDCR TYPE 0.75" PANAMETRICS XDCR FREQ. 5.0 Mhz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. ____

AVG. PEAK OUTPUT 0.2 v GATE DELAY 15-20 μs GATE WIDTH 7 μs

SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION TRANS

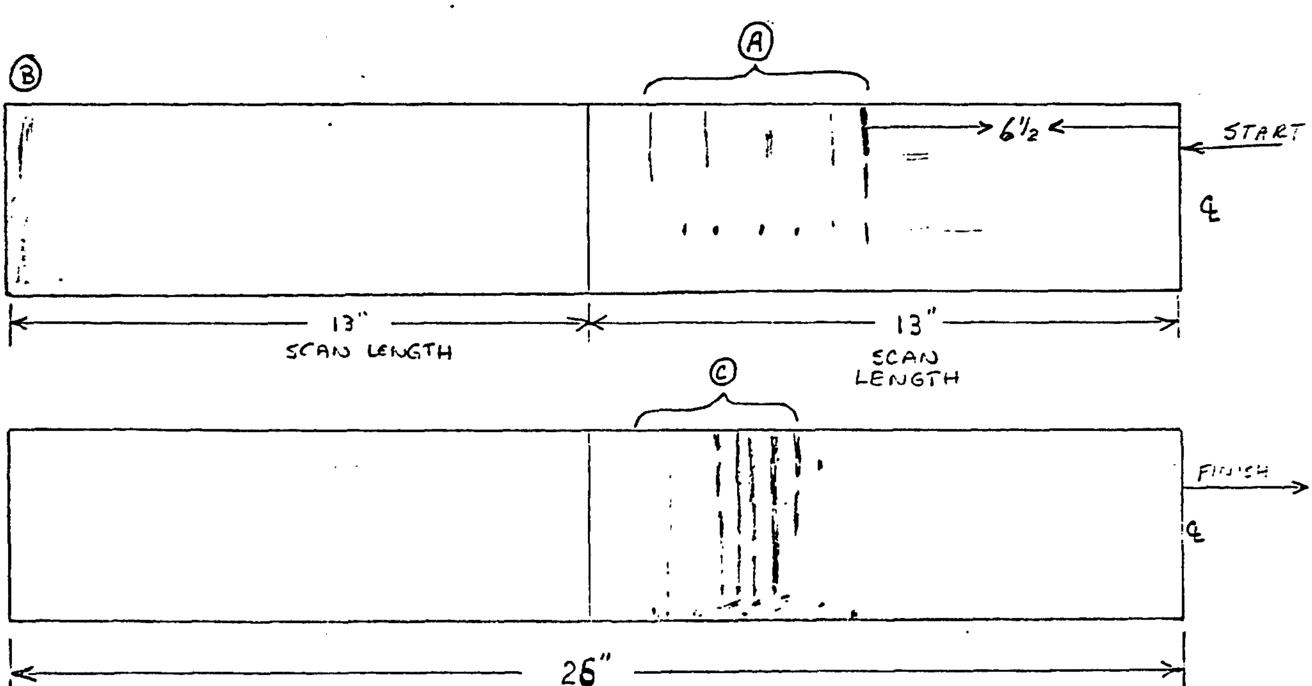
INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.

SCAN THIS SIDE

RESULTS: (A) NARROW INDICATIONS LEVEL 4. SMALL AREA (3) (2/3t AT PLY ENDS)

(B) END OF SPRING

(C) SEE (A)



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-20-80

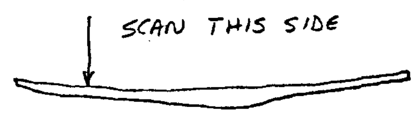
SPRING No. R-4 SN 1 #2 XDCR TYPE 0.75" PANAMETRICS XDCR FREQ. 5.0 Mhz

REP. RATE 5K ENERGY 2 GAIN 40 dB ATTEN. 16 dB

AVG. PEAK OUTPUT 0.2V GATE DELAY 15-20 NS GATE WIDTH 7 NS

SCAN SPEED 7 IPS INDEX INCR. 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.

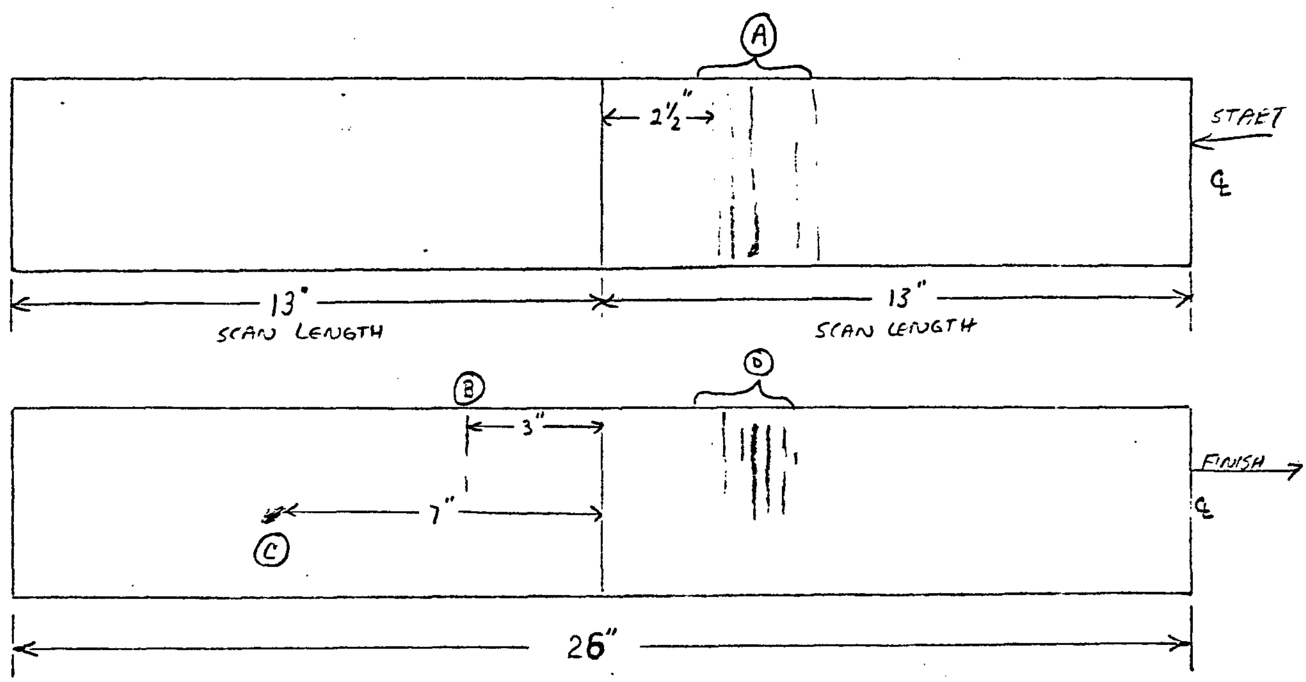


RESULTS: (A) AREA 3 LEVEL 3 NARROW INDICATIONS 2/3 t

(B) AREA 2 LEVEL 3 SAME AS (A)

(C) AREA 1 LEVEL 3 1/2 t

(D) SEE (A)



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-20-80

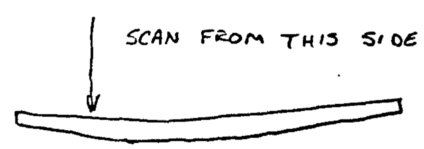
SPRING No. R-4 SN 1 #3 XDCR TYPE 0.75" PANAMETRICS XDCR FREQ. 5.0 Mhz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 16 dB

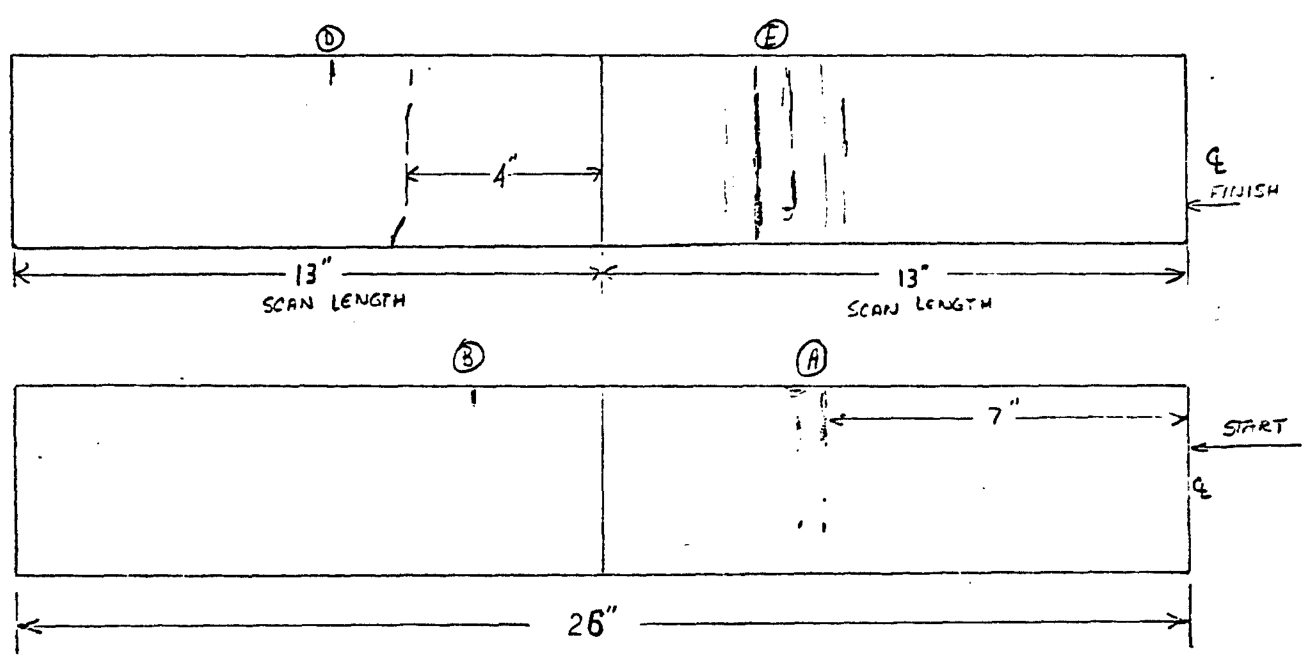
AVG. PEAK OUTPUT 0.2 V GATE DELAY 15-20 μS GATE WIDTH 7 μS

SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: (A) LEVEL 3 AREA 2 2/3 t (PLY ENDS)
(B) LEVEL 2 AREA 1 1/2 t
(C) LEVEL 3 AREA 2 1/2 t
(D) LEVEL 2 AREA 1 1/2 t
(E) LEVEL 3 AREA 2 1/2 + 2/3 t (see (E))



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-24-80

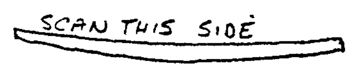
SPRING No. R-4 SN 1 #4 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz.

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 12-18 dB

AVG. PEAK OUTPUT 0.2 V GATE DELAY 10.20 NS GATE WIDTH 7 NS

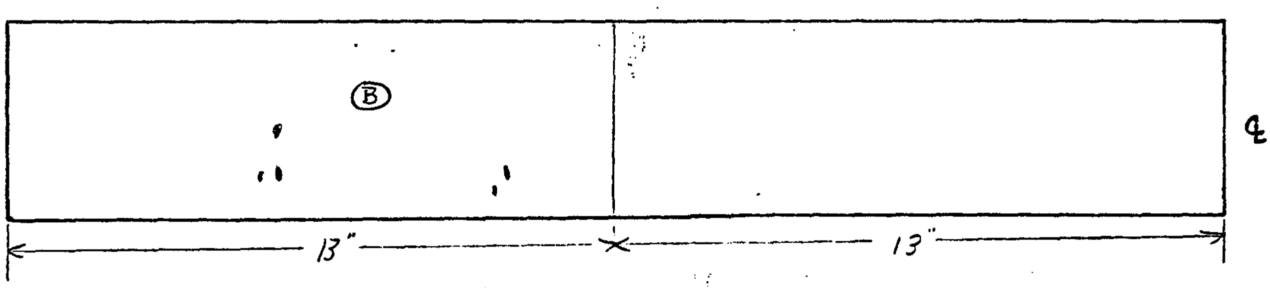
SCAN SPEED 6 IPS INDEX INCR. 0025 in. INDEX DIRECTION TRANS

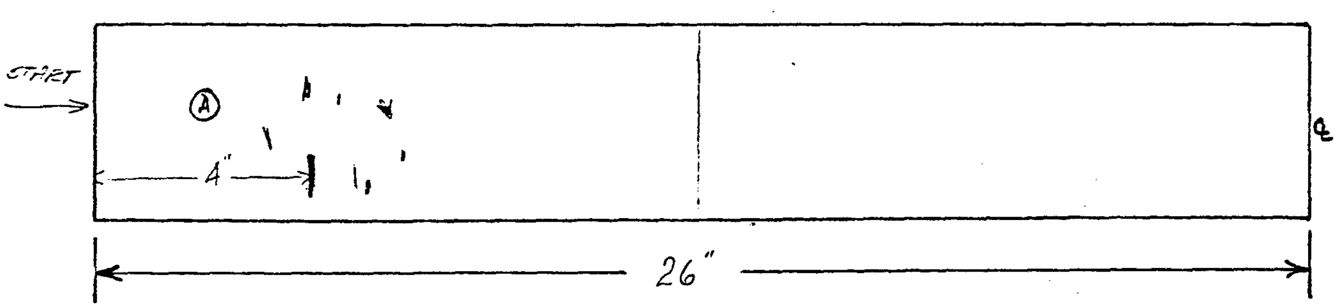
INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. ≤ BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: (A) LEVEL 2 AREA 2 SEVERAL SMALL DISCONTINUITIES ALL LOCATED AROUND 1/2 t.

(B) SEE (A)





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-24-80

SPRING No. R-4 SN 1# 5 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz.

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 12-18 dB

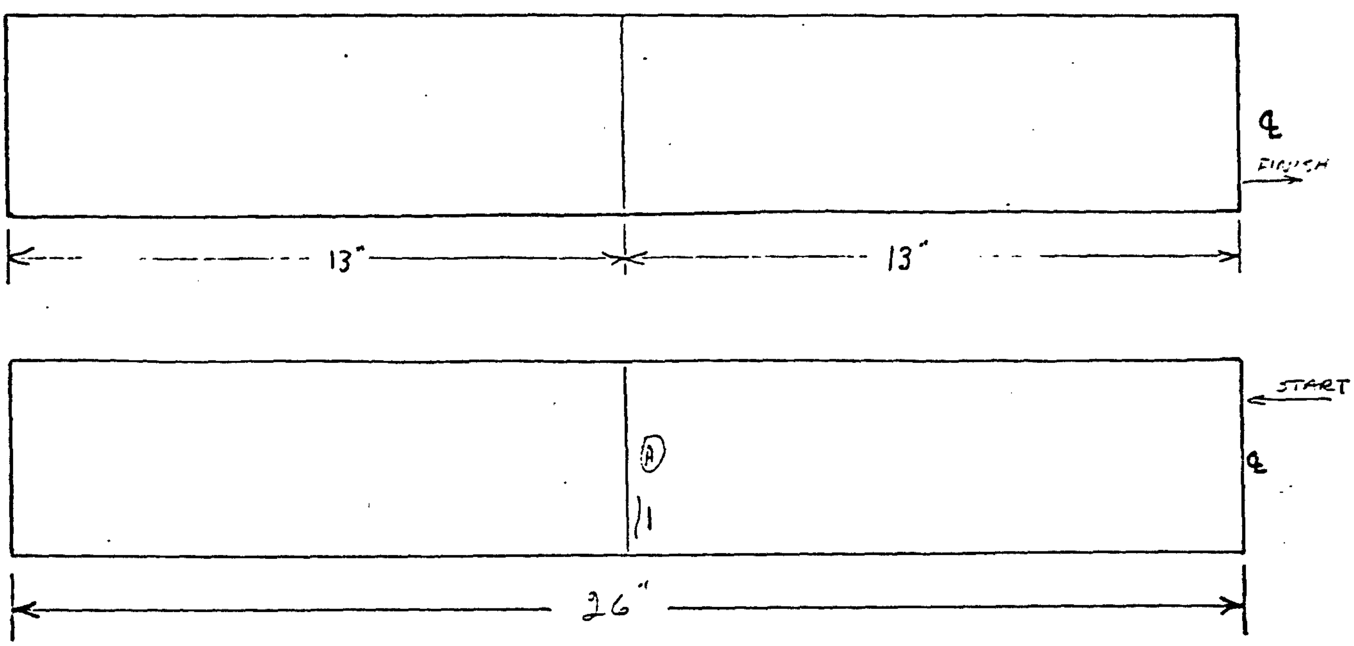
AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 NS GATE WIDTH 7 NS

SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. ∢ BACK REFLECTION	6. < 4 SQ. IN.

SCAN THIS SIDE

RESULTS: (A) LEVEL 2 AREA 1 1/3 t low level indication



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-17-80

SPRING No. R-4 SN 1 #6 XDCR TYPE 0.75 PANAMETRICS XDCR FREQ. 5.0 mhz

REP. RATE 5K ENERGY 2 GAIN 40 dB ATTEN. 20 dB

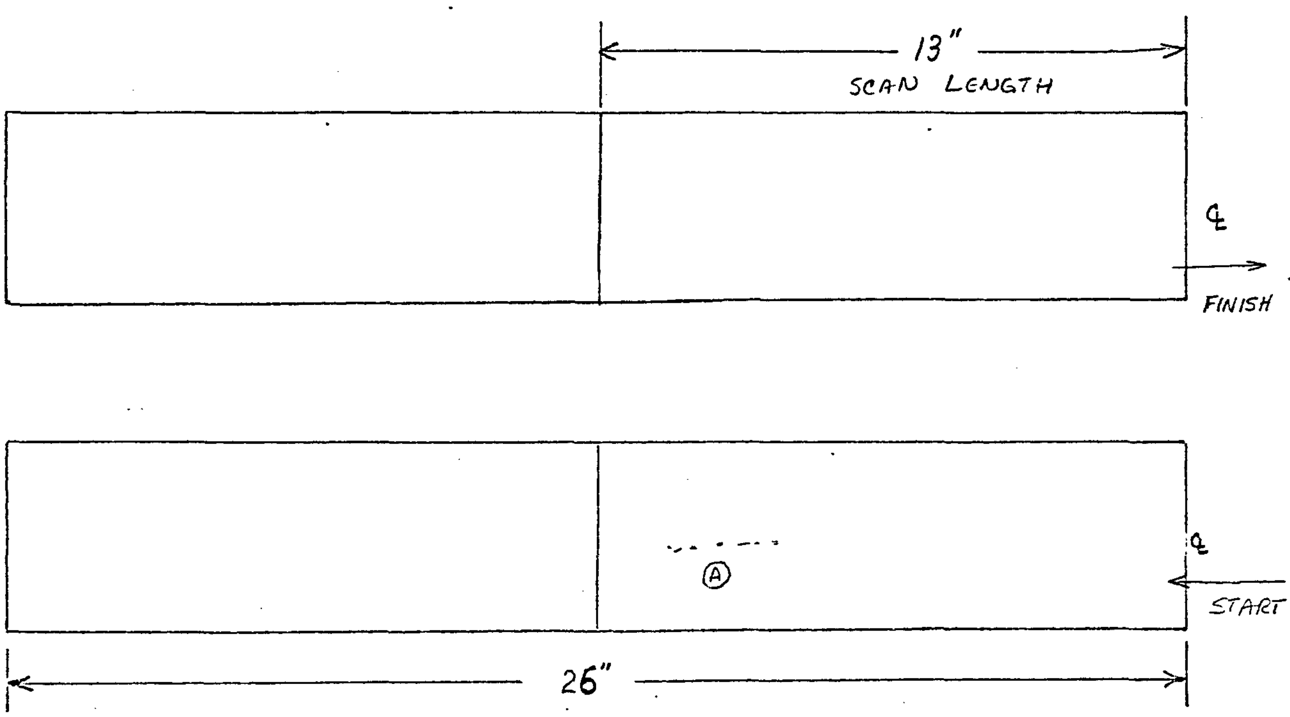
AVG. PEAK OUTPUT 0.2V GATE DELAY 15-20 µs GATE WIDTH 7 µs

SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION TRANS

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ IN.

SCAN THIS SIDE

RESULTS: (A) LEVEL 2 INDICATIONS - AREA 1 - PROBABLY PLY ENDS



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 11-3-80

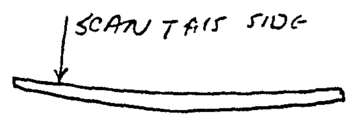
SPRING No. R-5 SN 1 #1 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 8-16 dB

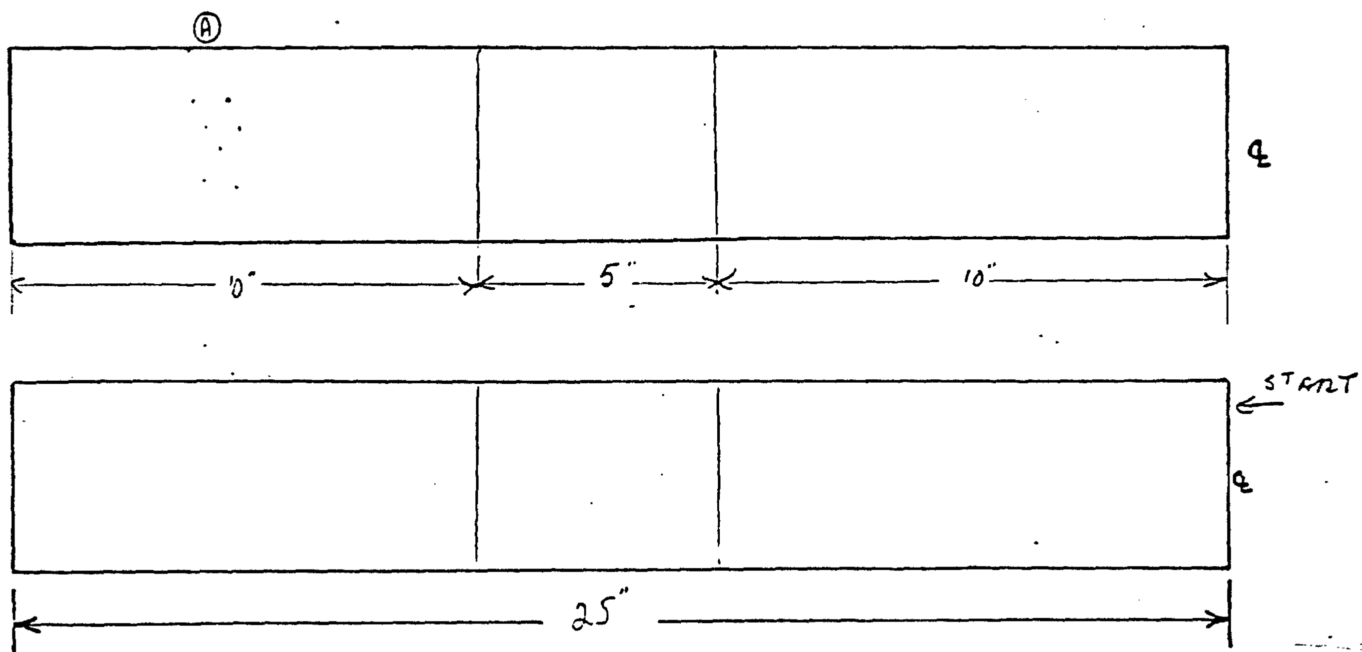
AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 NS GATE WIDTH 5-10 NS

SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION VERT

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: A LEVEL 2 AREA 1 1/2t



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 11-3-80

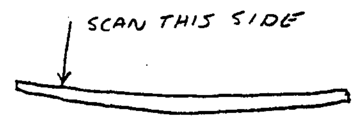
SPRING No. R-5 SN 1 #2 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 6-16 dB

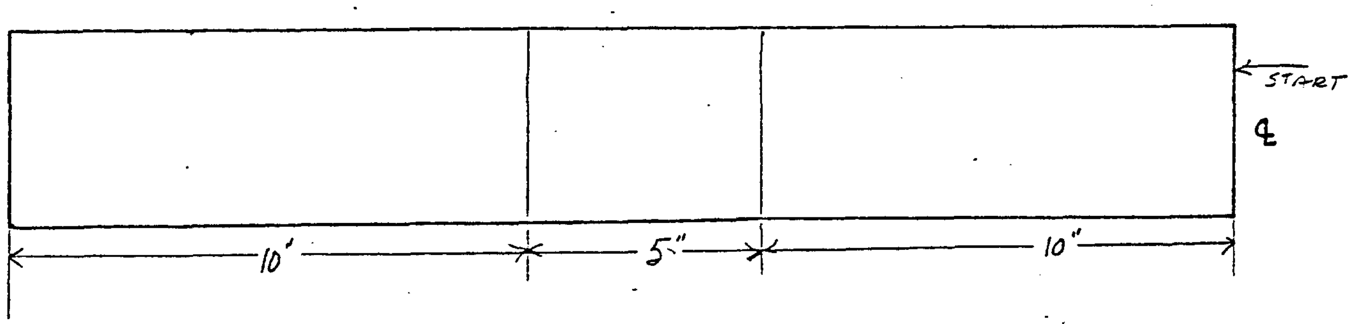
AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 NS GATE WIDTH 5-10 NS

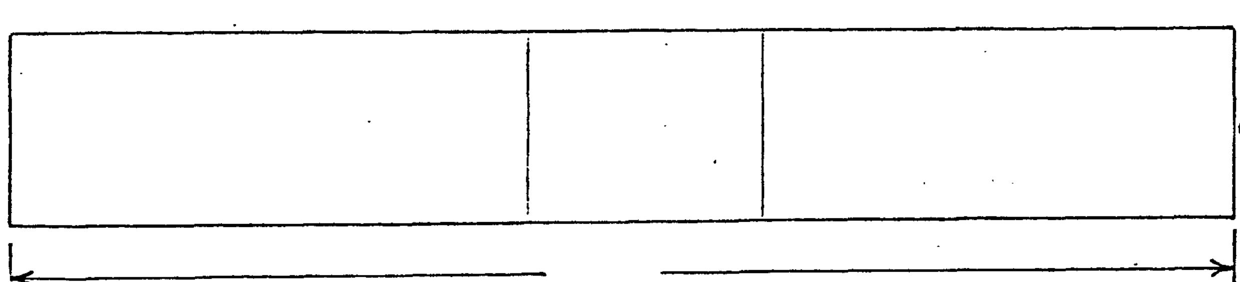
SCAN SPEED 6 IPS INDEX INCR. 0.025 in. INDEX DIRECTION VERT

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: NO SIGNIFICANT FLAW INDICATIONS





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 11-3-80

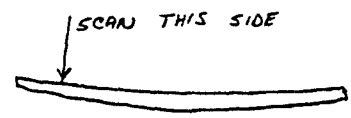
SPRING No. R-5 SN 1 #3 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 8-16 dB

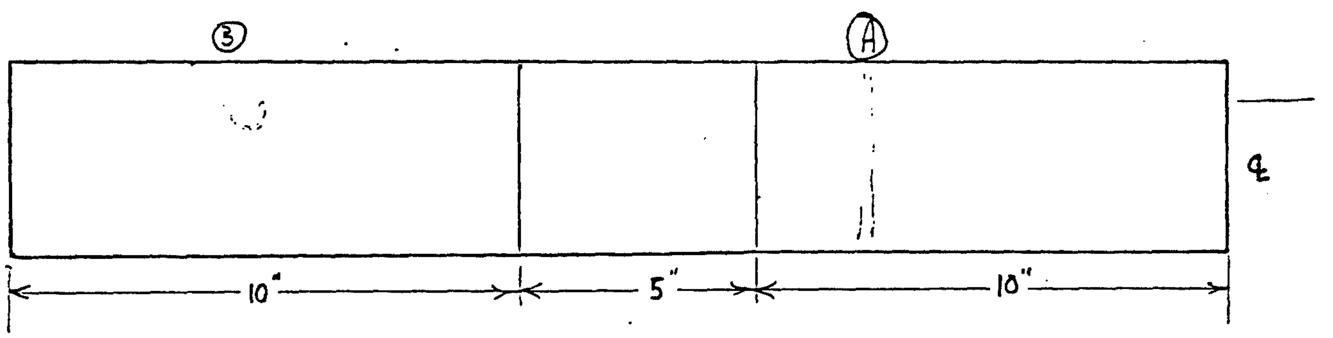
AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 μS GATE WIDTH 5-10 μS

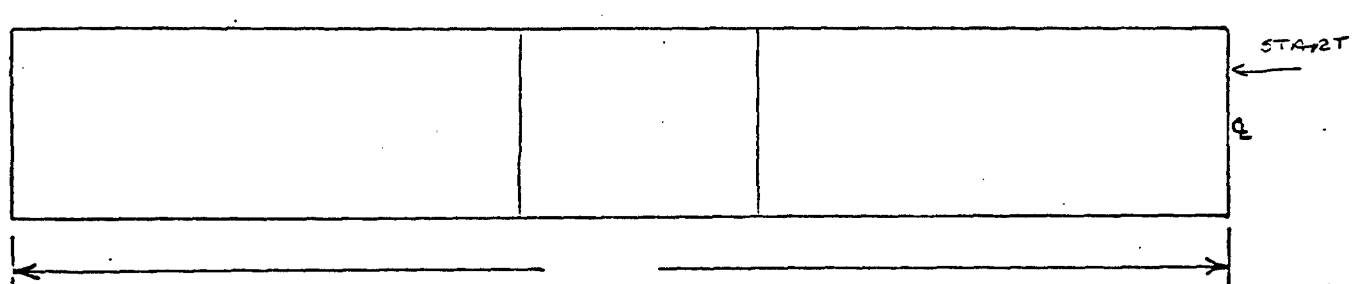
SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION VERT

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: (A) LEVEL 2 AREA 2 2/3 t (PLY ENDS)
(3) LEVEL 2 AREA 2 SLIGHTLY MORE THAN 1/2 t





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 11-4-80

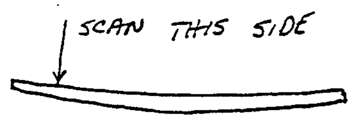
SPRING No. R-5 SN 1 # 4 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 10-18 dB

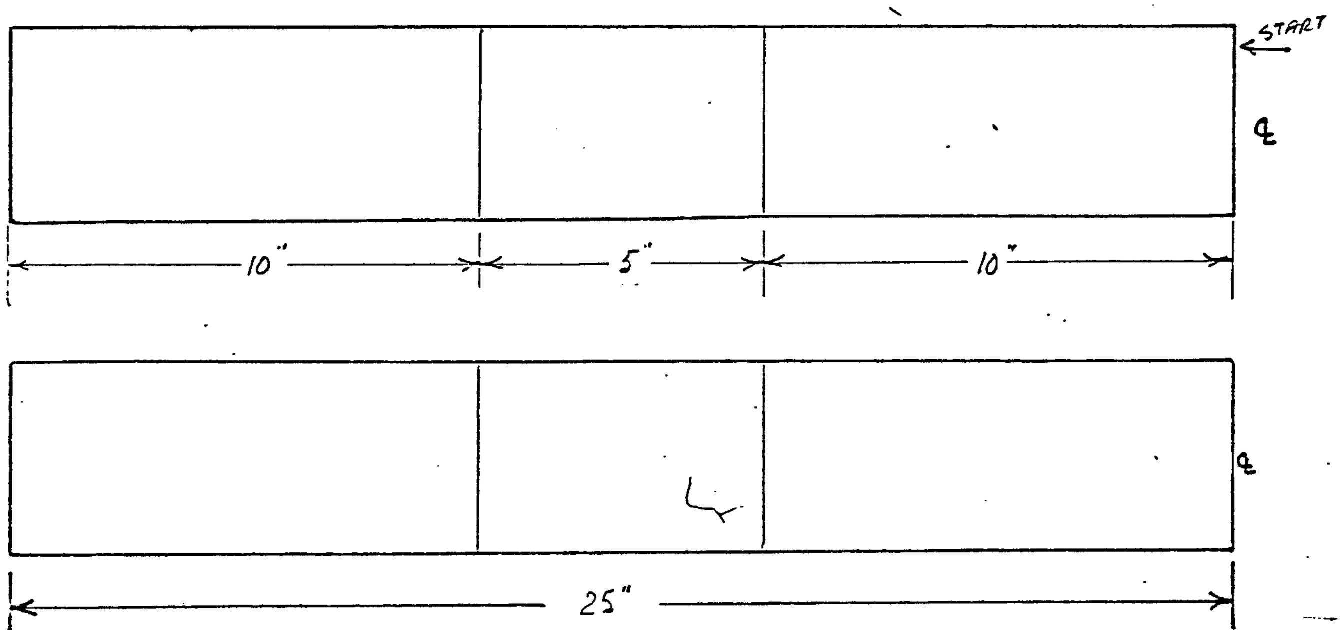
AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 NS GATE WIDTH 5-10 NS

SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION VERT.

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: NO SIGNIFICANT FLAW INDICATIONS



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 11-4-80

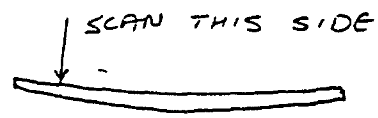
SPRING No. R-5 SN 1 # 5 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 10-18 dB

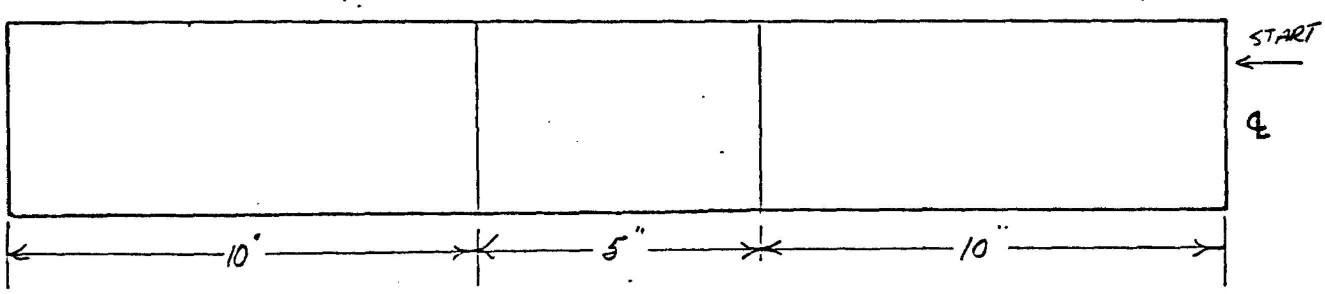
AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 NS GATE WIDTH 5-10 NS

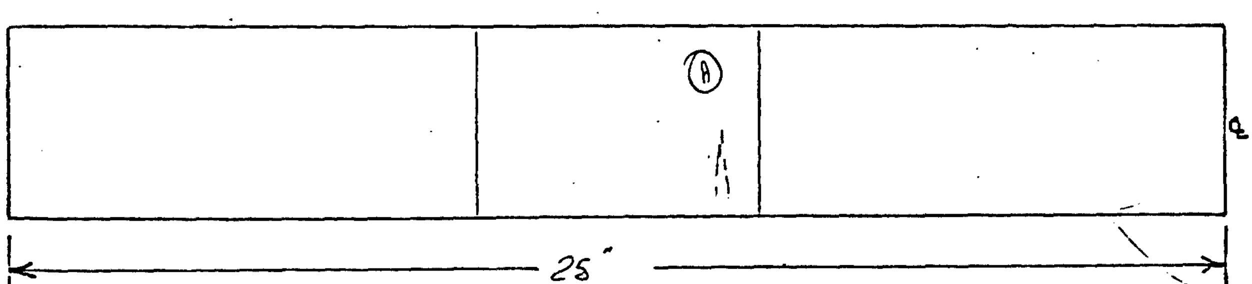
SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION VERT

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ IN.



RESULTS: A level 2 AREA 2 2/3 t (PLY END)





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 11-4-80

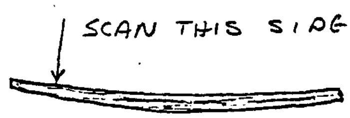
SPRING No. R-5 SN 1 #6 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. ______

AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 μS GATE WIDTH 5-10 μS

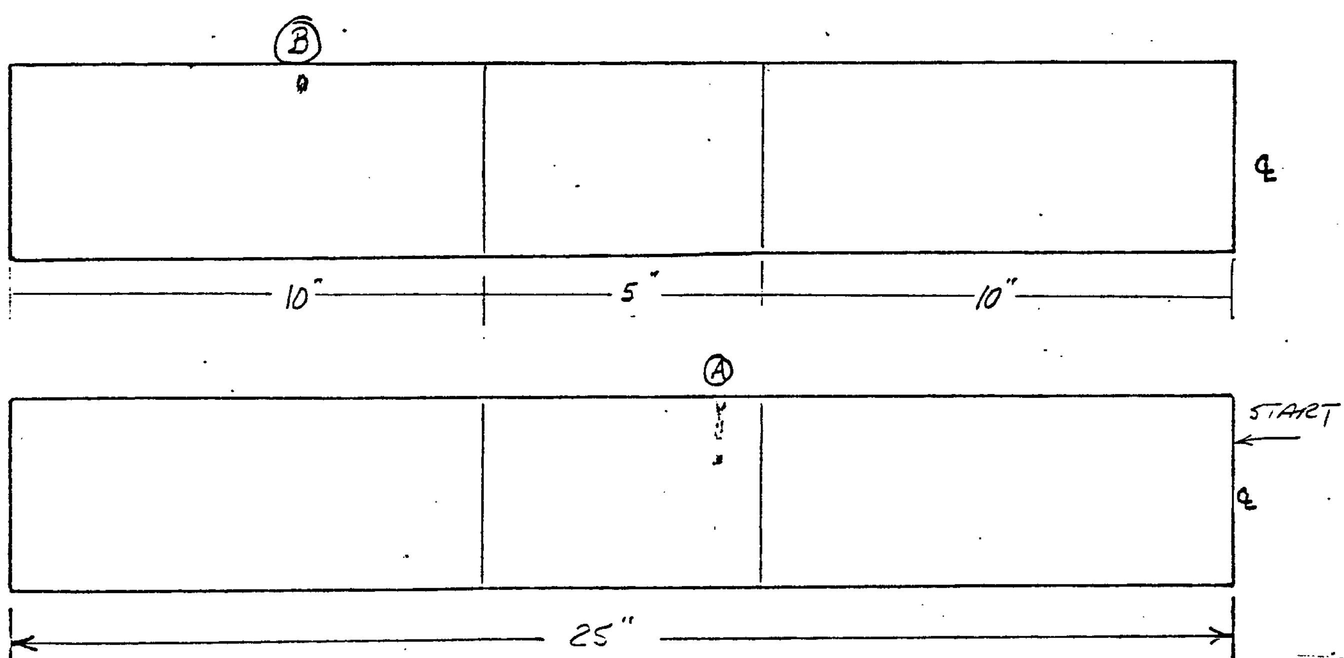
SCAN SPEED 6 IPS INDEX INCR. 0.025 in. INDEX DIRECTION VERT

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: (A) LEVEL 2 AREA 2 2/3t

(B) LEVEL 2 AREA 1 1/2t



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 11-4-80

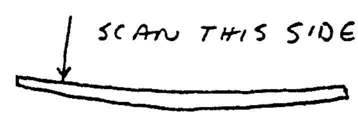
SPRING No. R-5 SN 1 # 7 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 10-20 dB

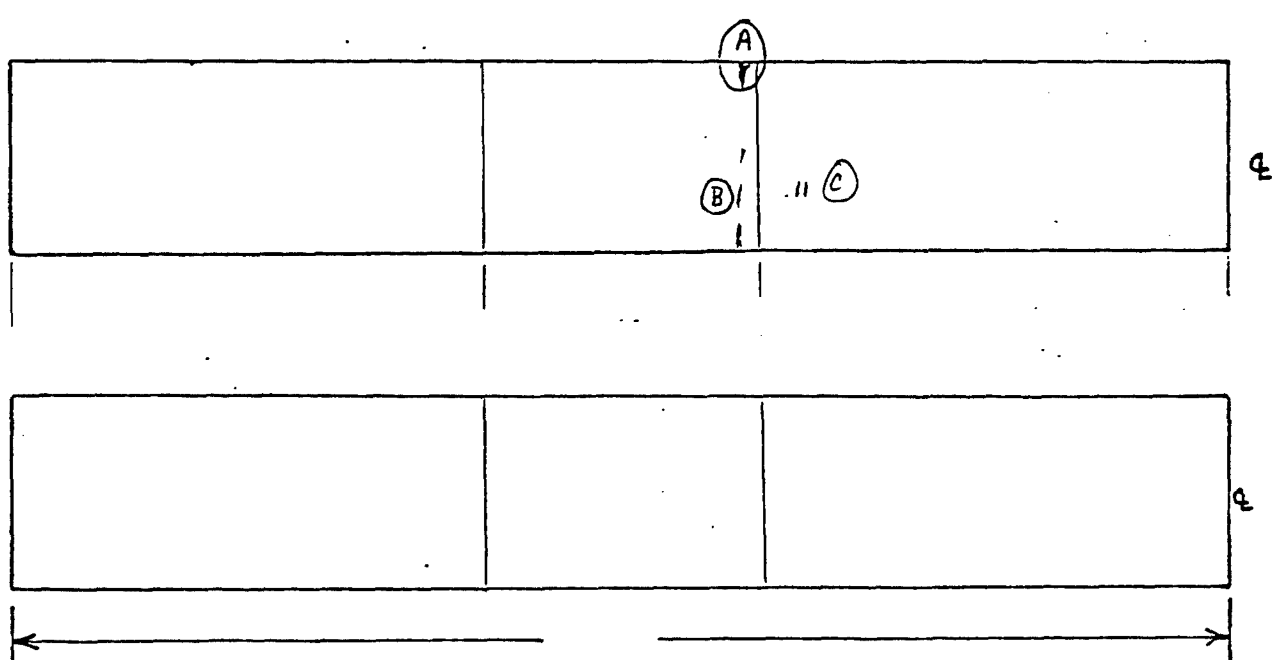
AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 NS GATE WIDTH 5-10 NS

SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION VERT

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: (A) LEVEL 2 AREA 2 JUST INSIDE FRONT SURFACE REFLECTION.
(B) Level 2 AREA 2 1/2 t
(C) LEVEL 2 AREA 1 2/3 t



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-30-80

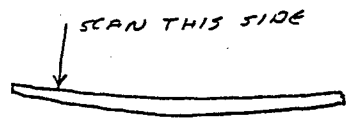
SPRING No. R-6 SN 1 #1 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 12-18 dB.

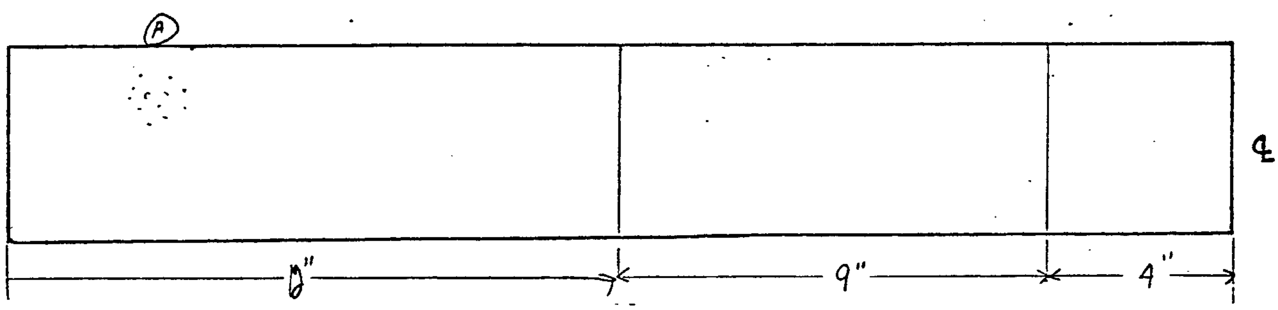
AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 NS GATE WIDTH 10 NS

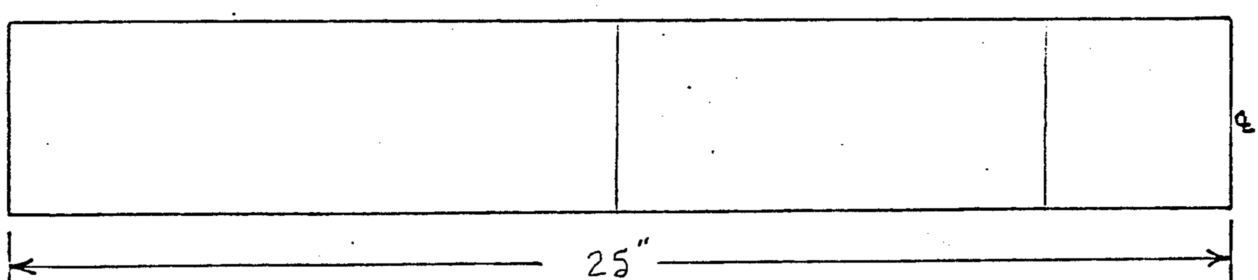
SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION VERT

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ IN.



RESULTS: (A) LEVEL 1 AREA 1 SEVERAL SMALL INDICATIONS IN THIS AREA





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-30-86

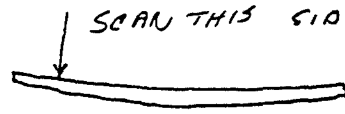
SPRING NO. R6 SN1 #2 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 12-18 dB

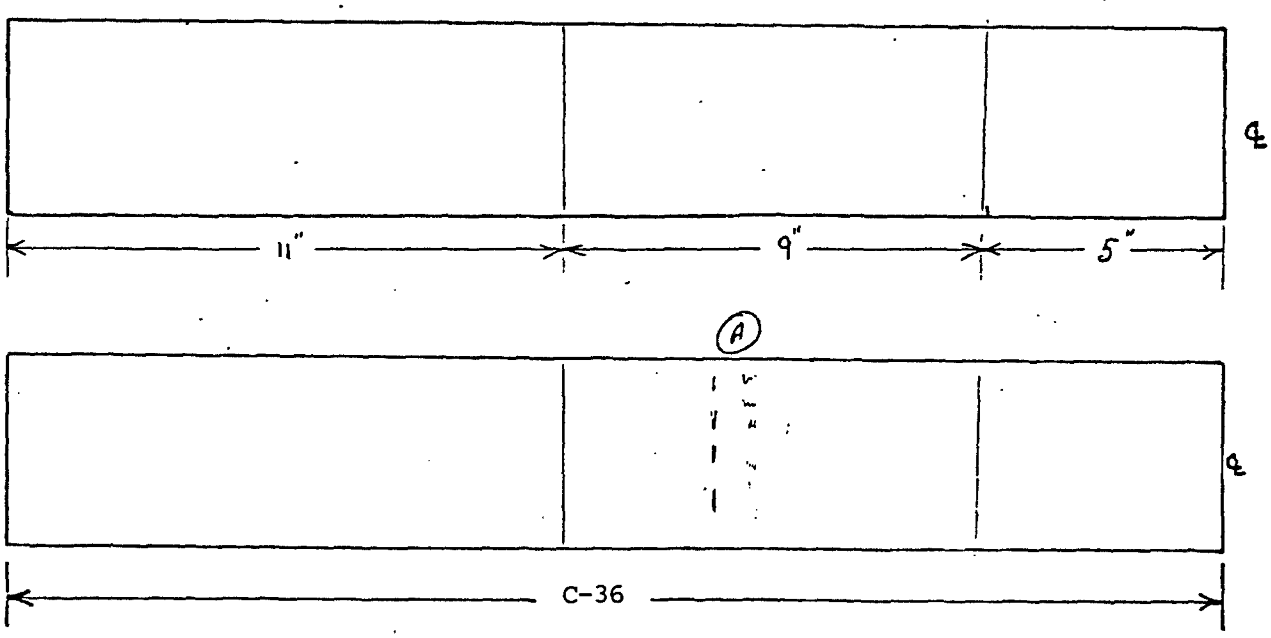
AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 US GATE WIDTH 10 US

SCAN SPEED 6 IPS INDEX INCR. 0.025 in. INDEX DIRECTION VERT

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. € BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: (A) SMALL LEVEL 2 AREA 2 DISCONTINUITIES 2/3t (PLY ENDS)



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-31-80

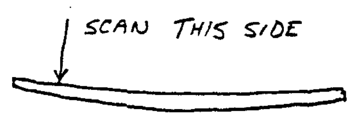
SPRING No. R-6 SN 1 #4 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 10-18 dB

AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 μS GATE WIDTH 5-10 μS

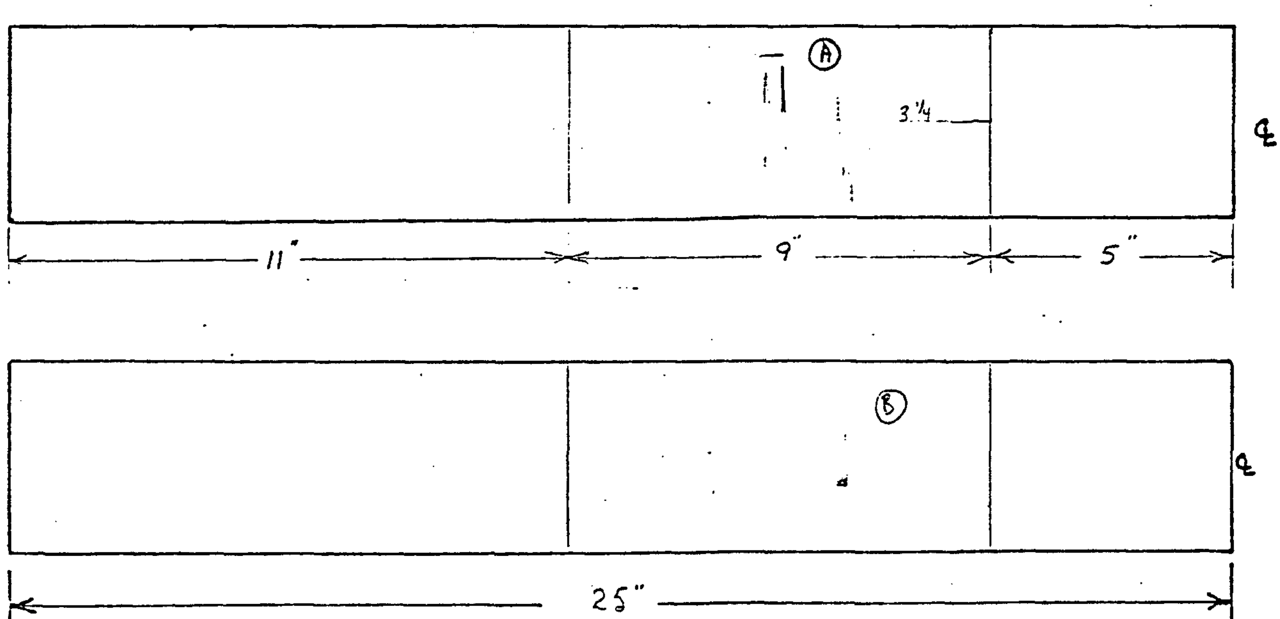
SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION VERT

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. ∢ BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: (A) LEVEL 2 AREA 2 LOCATED AROUND 2/3 t - SEVERAL SMALL INDICATIONS

(B) LEVEL 2 AREA 1 2/3 t



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-31-80

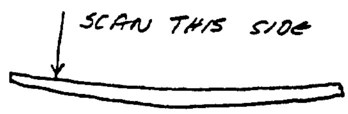
SPRING No. R-6 SN1 #5 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 8-16 dB

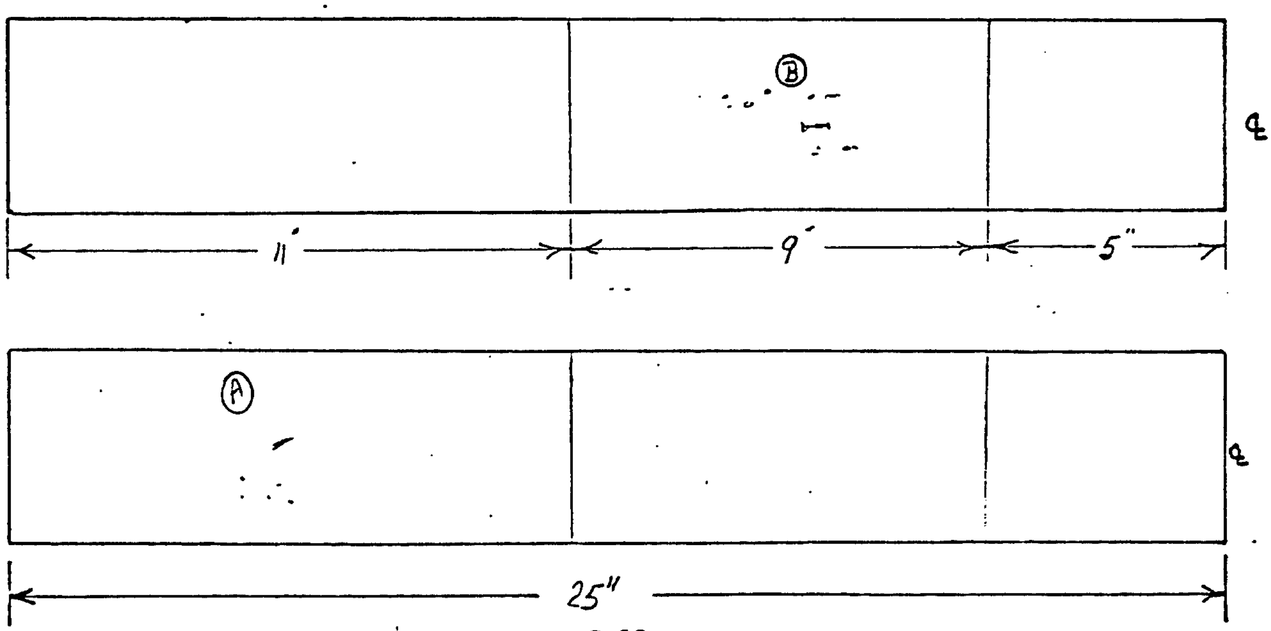
AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 NS GATE WIDTH 5-10 NS

SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION VERT

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: (A) SEVERAL LEVEL 2 AREA 1 INDICATIONS 1/2 - 2/3 t
(B) LEVEL 2 AREA 1 2/3 t SEVERAL SMALL INDICATIONS



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 11-3-80

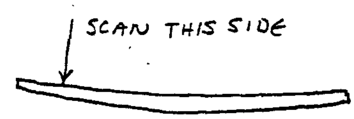
SPRING No. R-6 SN 1 # 6   XDCR TYPE 0.50 PANAMETRICS   XDCR FREQ. 2.25 MHz

REP. RATE 5k   ENERGY 2   GAIN 40 dB   ATTEN. 8-16 dB

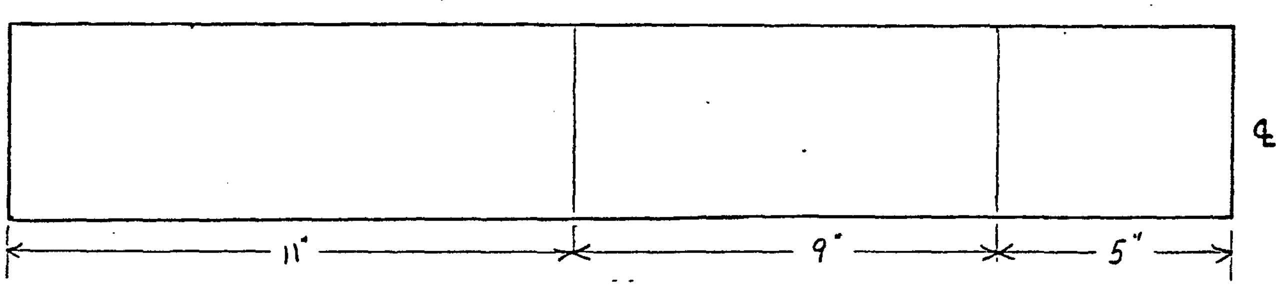
AVG. PEAK OUTPUT 0.2 V   GATE DELAY 10-20 NS   GATE WIDTH 5-10 NS

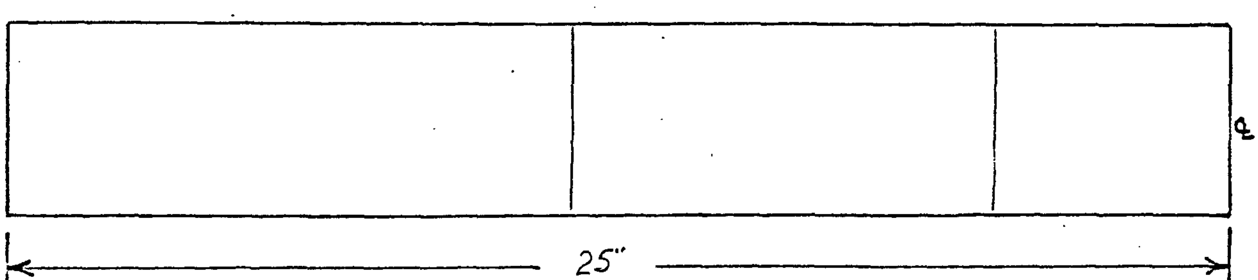
SCAN SPEED 6 IPS   INDEX INCR 0.025 in.   INDEX DIRECTION VERT.

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: NO SIGNIFICANT FLAW INDICATIONS





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 11-3-80

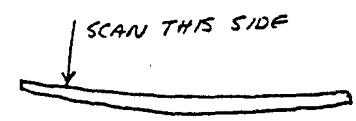
SPRING No. R-6 SN 1 #7 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 8-18 dB

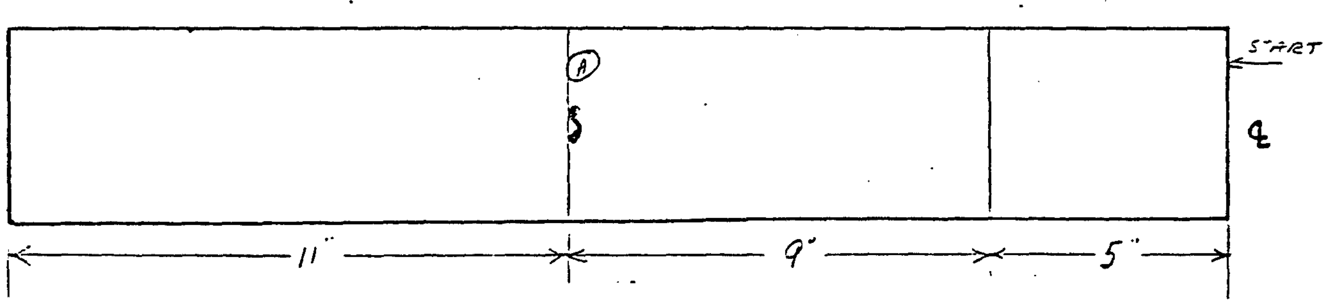
AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 NS GATE WIDTH 5-10 US

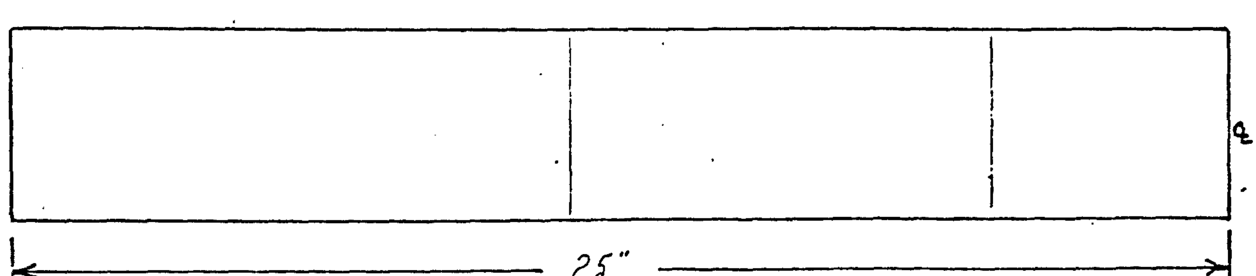
SCAN SPEED 6 IPS INDEX INCR 0.025" in. INDEX DIRECTION VERT

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. <4 SQ. IN.



RESULTS: (A) LEVEL 2 AREA 2 1/2 t





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-28-80

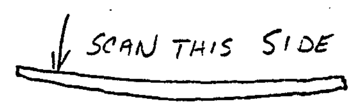
SPRING No. R-7 SN 1 # 1 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz.

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 12-18 dB

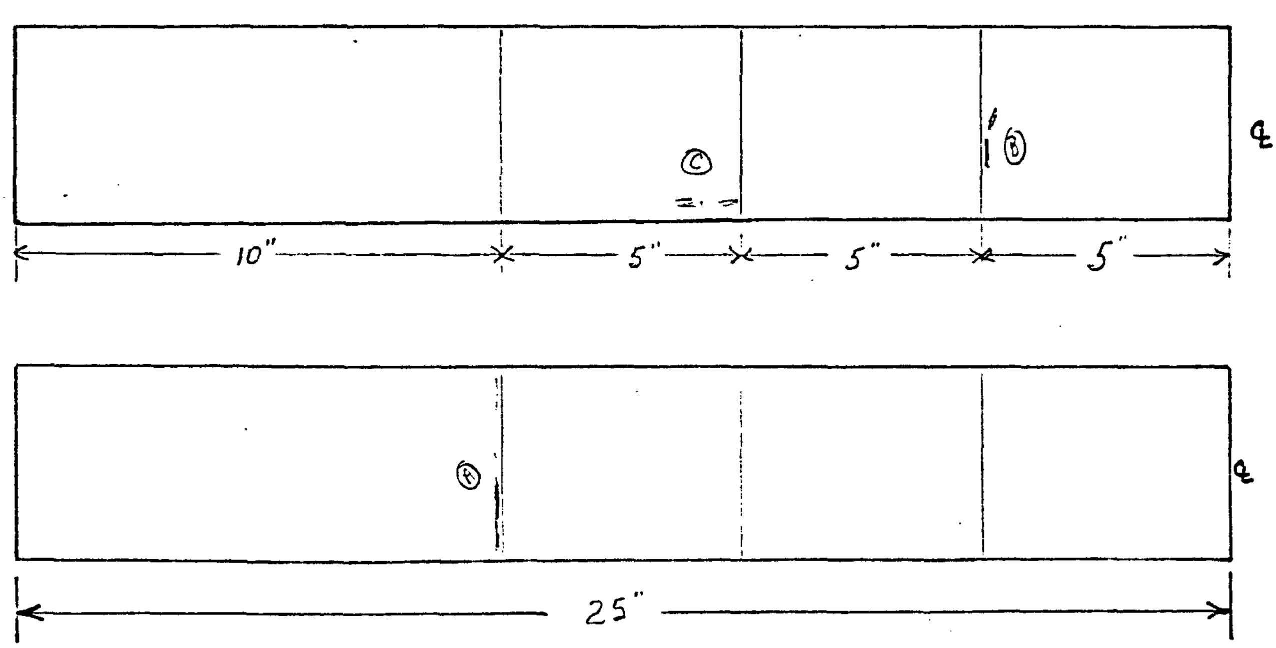
AVG. PEAK OUTPUT 0.2V GATE DELAY 10-20 NS GATE WIDTH 5-10 NS

SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION VERT

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION.	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ IN.



RESULTS: (A) INDICATION CAUSED BY BACK WALL CURVATURE AND NOT BY DISCONTINUITY
(B) LEVEL 2 AREA 2 APPROX 1/3 t.
(C) LEVEL 2 AREA 2 1/3 t



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10·28·80

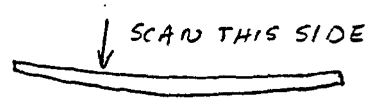
SPRING No. R-7 S/N 1 #2 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz.

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 12-18 dB

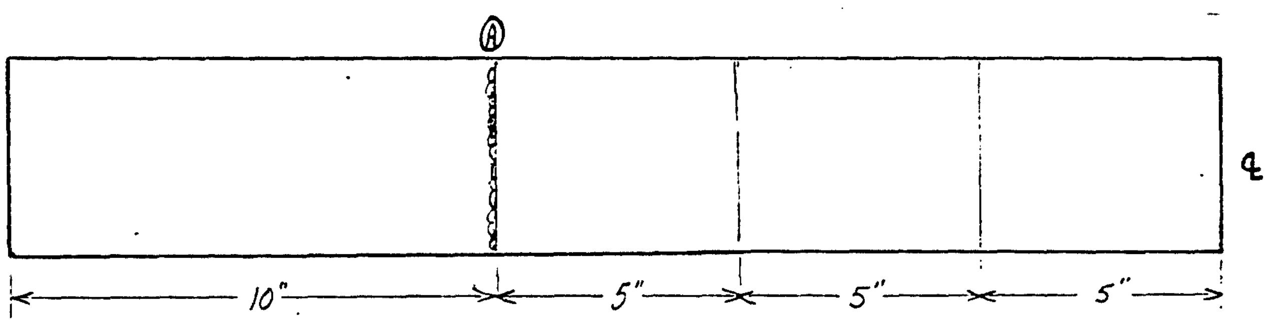
AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 NS GATE WIDTH 5-10 NS

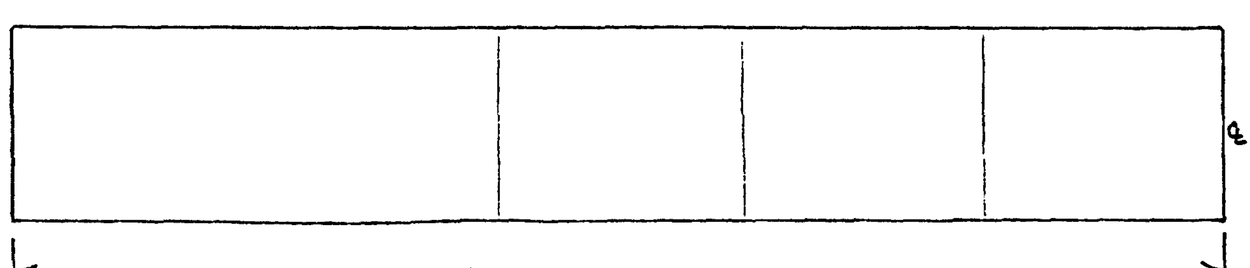
SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION VERT.

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. ∢ BACK REFLECTION	6. <4 SQ IN.



RESULTS: (A) SIGNAL LOSS DUE TO CURVATURE OF THE SPRING AND LEVEL 2 INDICATION AT 1/2t (PLY END)





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-29-80

SPRING No. R-7 SN 1 # 3 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz.

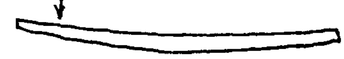
REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 8-16 dB

AVG. PEAK OUTPUT 0.2V GATE DELAY 10-20 NS GATE WIDTH 5-10 NS

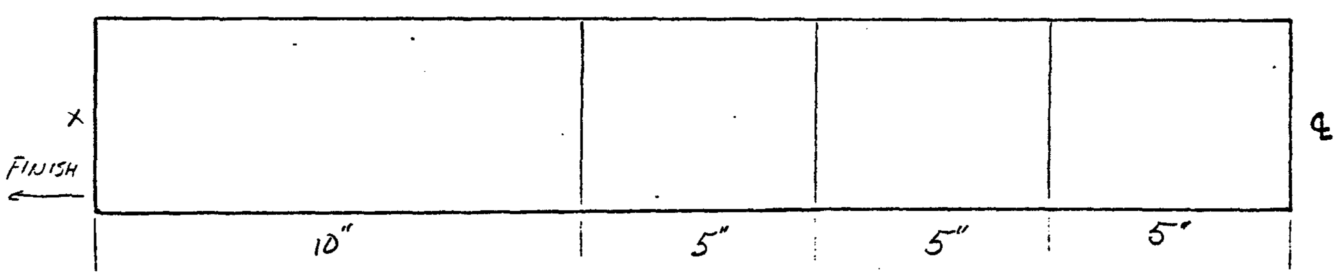
SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION → VERT.

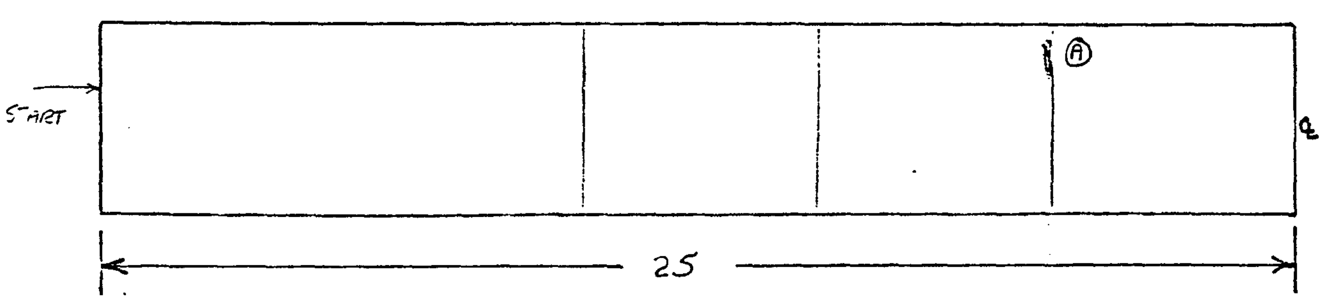
INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. ∢ BACK REFLECTION	6. <4 SQ. IN.

SCAN THIS SIDE



RESULTS: Ⓐ INDICATION CAUSED BY SIGNAL MOVING INTO BLANKING PULSE.
NO FLAW INDICATION





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-29-80

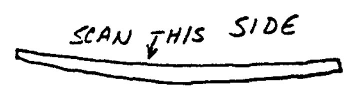
SPRING No. R-7 SN1 #4 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz.

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 10-18 dB

AVG. PEAK OUTPUT 0.2V GATE DELAY 10-20 μS GATE WIDTH 5-10 μS

SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION VERT

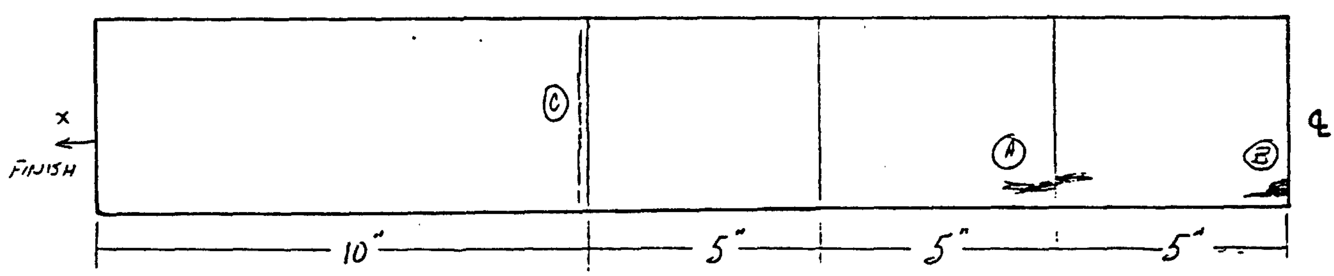
INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. ∈ BACK REFLECTION	6. < 4 SQ. IN.

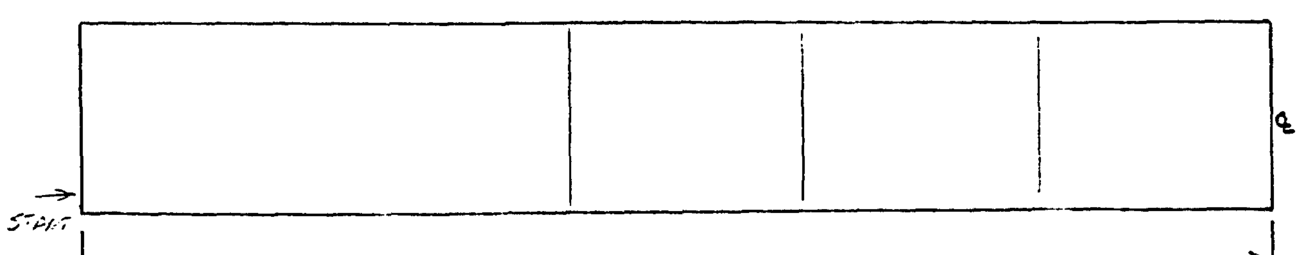


RESULTS: (A) LEVEL 3 AREA 2 1/3t

(B) NO FLAW INDICATION (BLANKING)

(C) LEVEL 3 AREA 2 1/2t





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-30-80

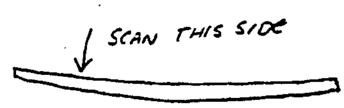
SPRING No. R-7 SN 1 # 5   XDCR TYPE 0.50 PANAMETRICS   XDCR FREQ. 2.25 MHz.

REP. RATE 5k   ENERGY 2   GAIN 40 dB   ATTEN. 8-16 dB

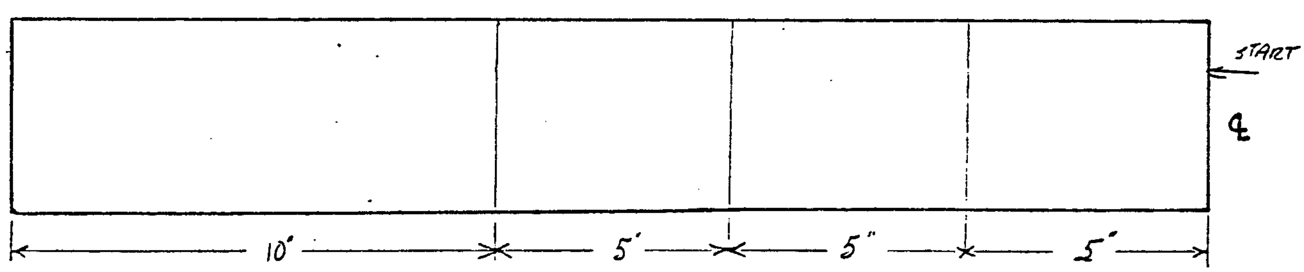
AVG. PEAK OUTPUT 0.2V   GATE DELAY 10-20 μS   GATE WIDTH 5-10 μS

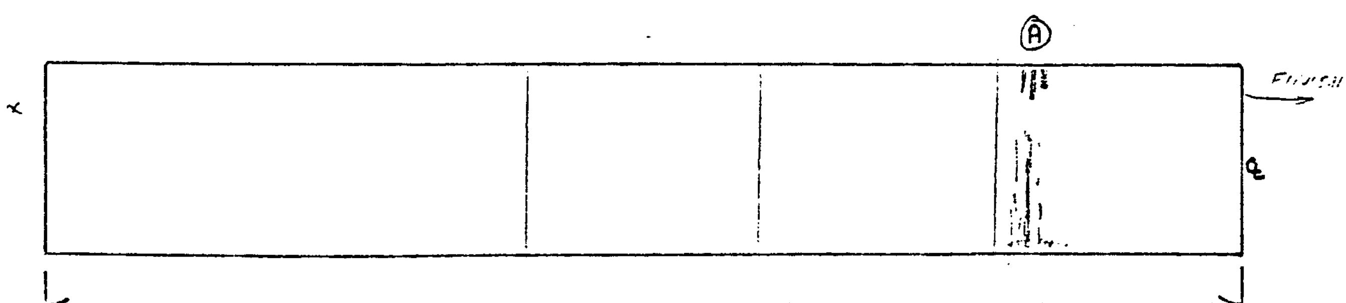
SCAN SPEED 6 IPS   INDEX INCR. 0.025 in.   INDEX DIRECTION [illegible]

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: LEVEL 3   AREA 3   LOCATED AT 2/3t (PROBABLY PLY ENDS)





TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-30-80

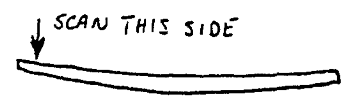
SPRING No. R-7 SN 1*6 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz.

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 8-16 dB

AVG. PEAK OUTPUT 0.2v GATE DELAY 10-20 NS GATE WIDTH 5-10 NS

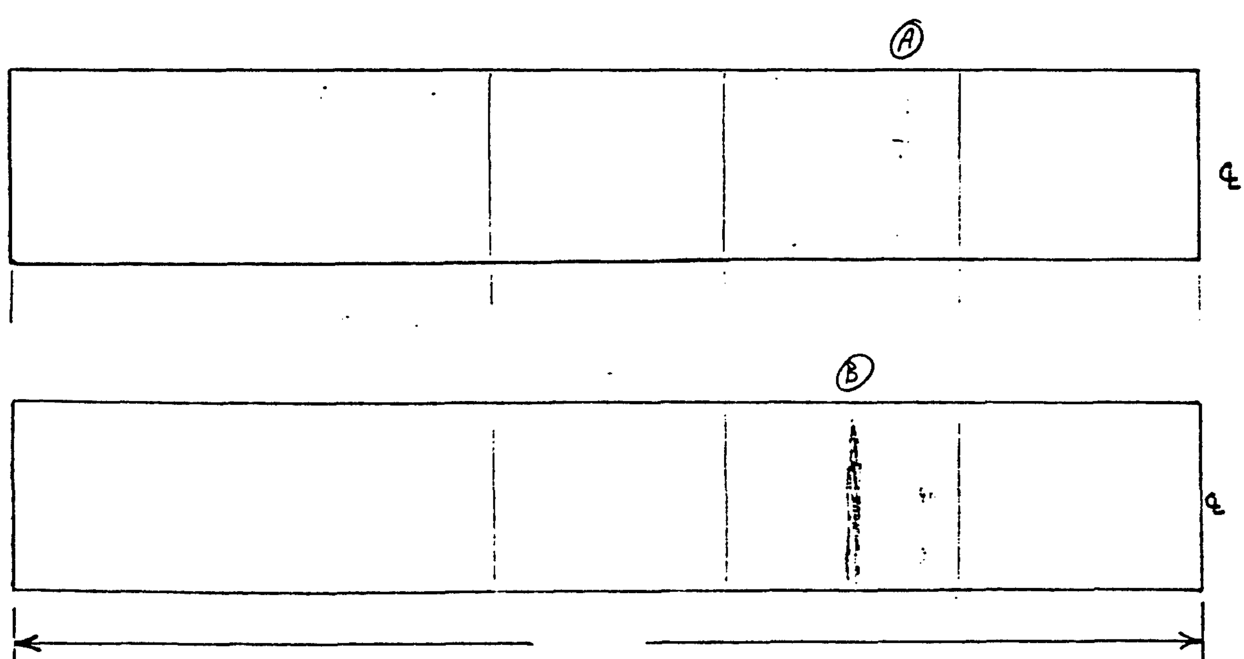
SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION VERT

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ IN.



RESULTS: (A) LEVEL 2 AREA 2 2/3 t

(B) LEVEL 3 AREA 3 1/3 t



TACOM LEAF SPRINGS

ULTRASONIC C-SCAN INSPECTION

DATE: 10-30-80

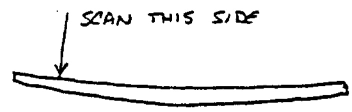
SPRING No. R-7 SN1 #7 XDCR TYPE 0.50 PANAMETRICS XDCR FREQ. 2.25 MHz

REP. RATE 5k ENERGY 2 GAIN 40 dB ATTEN. 8-16 dB

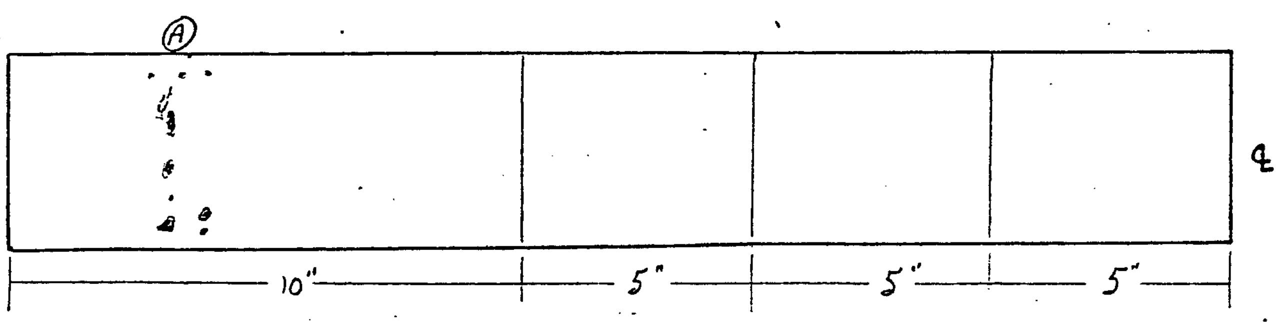
AVG. PEAK OUTPUT 0.2 V GATE DELAY 10-20 NS GATE WIDTH 5-10 NS

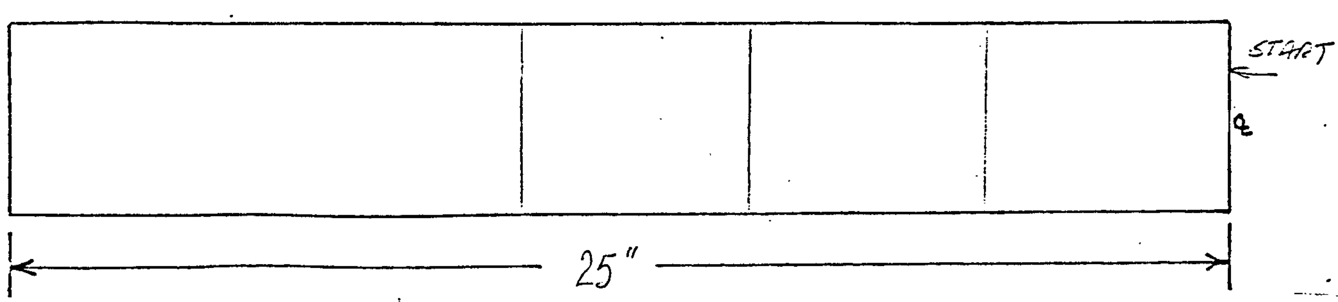
SCAN SPEED 6 IPS INDEX INCR 0.025 in. INDEX DIRECTION VERT

INDICATION LEVEL	INDICATION AREA
1. NOT DETERMINED	1. > 1/4 SQ. IN.
2. 25% BACK REFLECTION	2. 1/4 - 1/2 SQ. IN.
3. 50% BACK REFLECTION	3. 1/2 - 1 SQ. IN.
4. 75% BACK REFLECTION	4. 1-2 SQ. IN.
5. 100% BACK REFLECTION	5. 2-4 SQ. IN.
6. < BACK REFLECTION	6. < 4 SQ. IN.



RESULTS: (A) SEVERAL LEVEL 2, AREA 1+2 INDICATIONS LOCATED NEAR SURFACE SCANNED





C-SCAN FOR COMPOSITE TUBES

TACOM SHAFT

SCARF-JOINT C-SCAN

DATE: 9-1

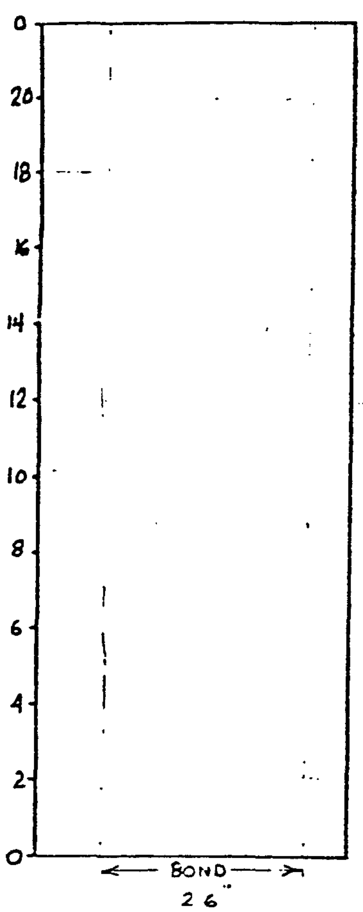
TUBE SN 4 XDCR TYPE (A) 0.5" 2.25mc 4"f (B) 0.5" 5.0mc uf MODE THRU-TRANSMISSION

ENERGY 2 GAIN 40dB ATTEN 24dB GATE WIDTH ______ GATE DELAY ______

INDEX DIRECTION ______ INDEX INCR. ______ SCAN SPEED ______

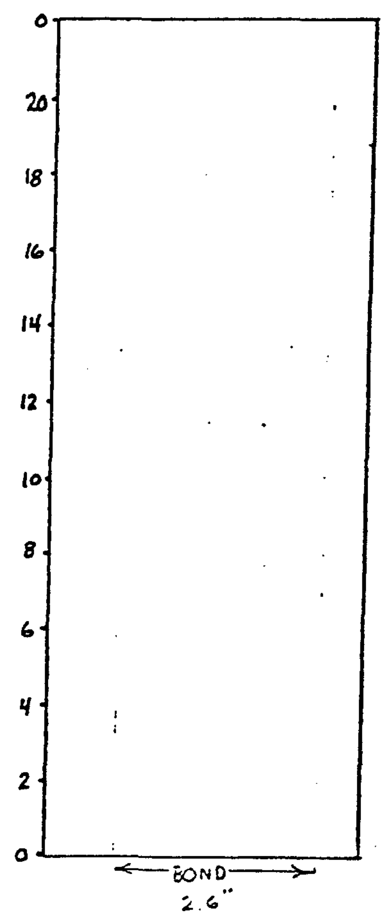
SCAN RESULTS: END (A)

NO SIGNIFICANT FLAW INDICATIONS IN GRAPHITE OR BOND AREA



SCAN RESULTS - END (B)

NO SIGNIFICANT FLAW INDICATIONS IN GRAPHITE OR BOND AREA



TACOM SHAFT
SCARF-JOINT C-SCAN
DATE: ____________

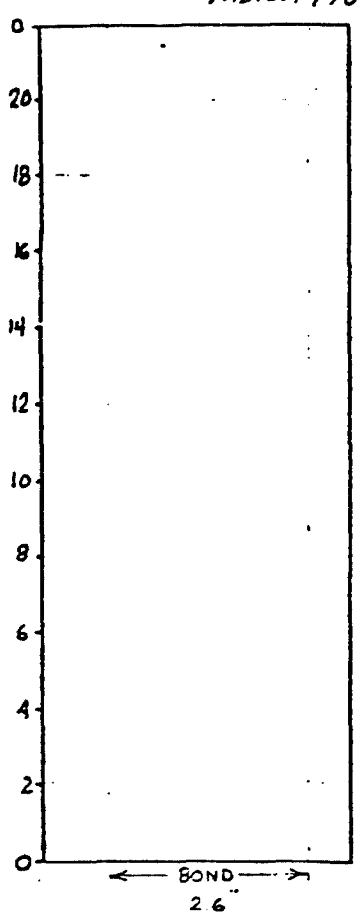
TUBE SN 5 XDCR TYPE (A) 0.5" 2.25mc 4"f (B) 0.5" 5.0mc uf MODE THRU-TRANSMISSION

ENERGY 2 GAIN 40dB ATTEN 24 dB GATE WIDTH ______ GATE DELAY ______

INDEX DIRECTION Vert INDEX INCR. .025 SCAN SPEED 5 IPS

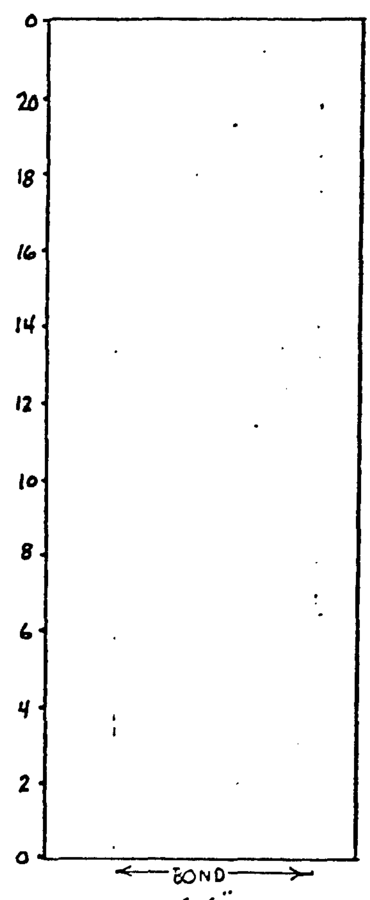
SCAN RESULTS: END (A)

NO SIGNIFICANT BOND-LINE FLAW INDICATIONS



SCAN RESULTS - END (B)

NO SIGNIFICANT BOND-LINE FLAW INDICATIONS.



TACOM SHAFT
SCARF-JOINT C-SCAN
DATE: ____________

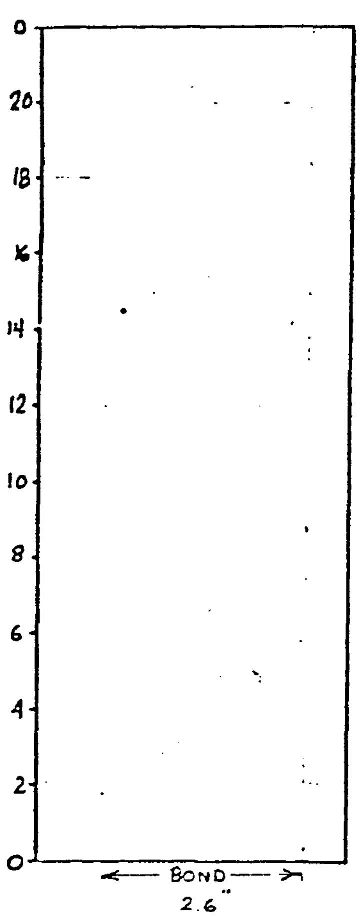
TUBE SN 7   XDCR TYPE (A) 0.5" 2.25mc 4" f (B) 0.5" 5.0mc uf   MODE THRU-TRANSMISSION

ENERGY 2   GAIN 40 dB   ATTEN 24 dB   GATE WIDTH ______   GATE DELAY ______

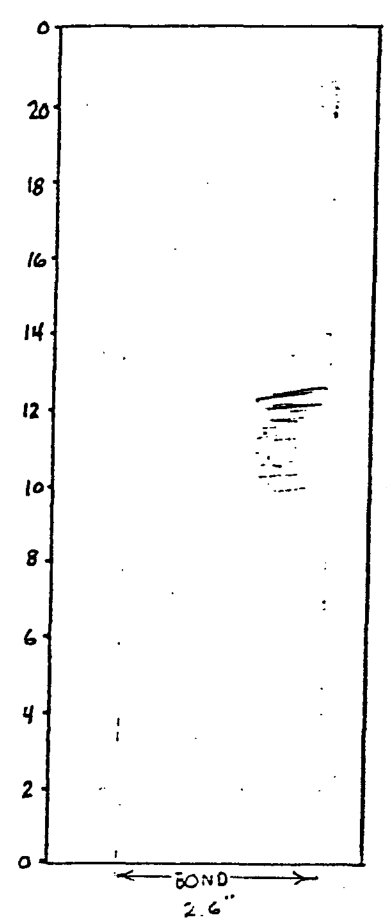
INDEX DIRECTION Trans   INDEX INCR. .025   SCAN SPEED 5 IPS

SCAN RESULTS: END (A)

NO FLAW INDICATIONS



SCAN RESULTS - END (B)



AREA OF SMALL VOIDS OR RESIN RICH AREAS IN GRAPHITE.

2/3 t from OUTSIDE

TACOM SHAFT

SCARF-JOINT C-SCAN

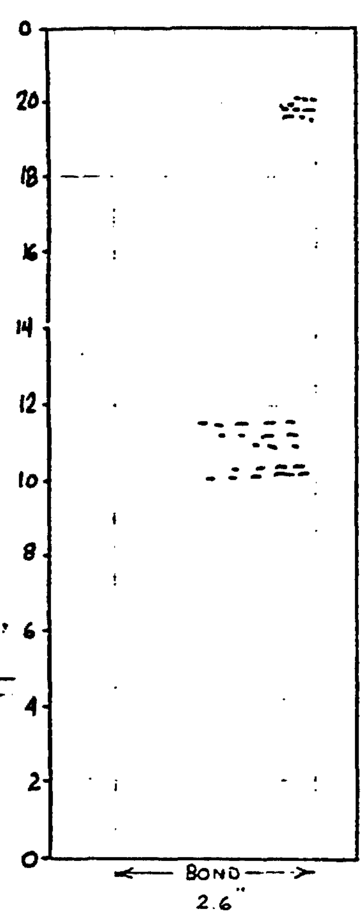
DATE: 9-10-81

TUBE SN ______ XDCR TYPE (A) .5", 5 mc 4"f (B) 0.5" 5 mc NF MODE THRU TRANSMISSION

ENERGY 2 GAIN 40dB ATTEN ≈ 18 dB GATE WIDTH 12 µs GATE DELAY 36 µs

INDEX DIRECTION TRANS INDEX INCR. .025" SCAN SPEED 4 IPS

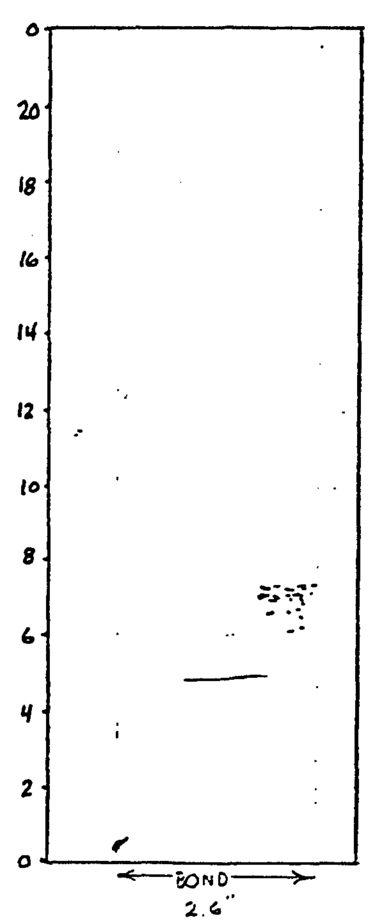
SCAN RESULTS: END (A)



SEE BELOW

POROSITY - LOSS OF SIGNAL IN BOND-LINE AREA.

SCAN RESULTS - END (B)



NO FLAW IN BOND - NOISE IN SIGNAL - RESIN RICH AREA OR POROSITY IN GRAPHITE LAMINATE.

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A DIVISION OF EXXON CORPORATION

TACOM SHAFT

SCARF-JOINT C-SCAN

DATE: 9-10-81

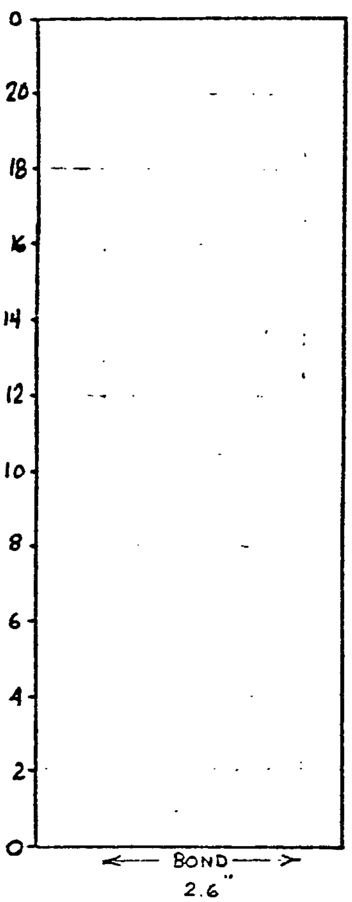
TUBE SN 7 XDCR TYPE (A) 0.5" 2.25mc 4"f (B) 0.5" 5mc UF MODE THRU TRANSMISSION

ENERGY 2 GAIN 40dB ATTEN ≈ 10dB GATE WIDTH 10NS GATE DELAY 45 NS

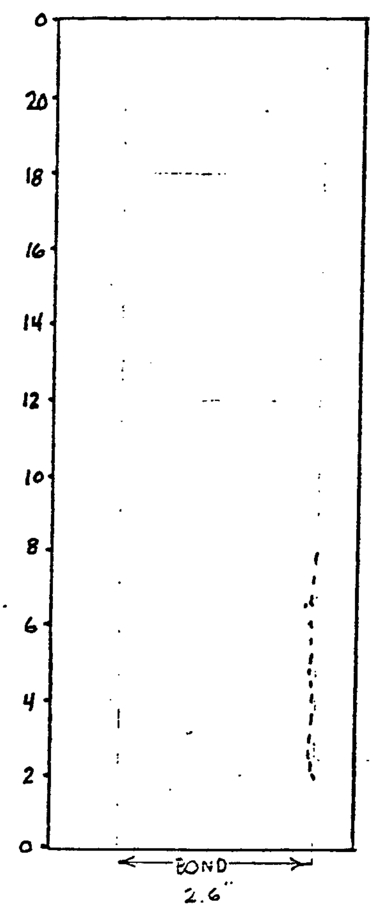
INDEX DIRECTION TRANS INDEX INCR. .025" SCAN SPEED 4 IPS

SCAN RESULTS: END (A)

NO FLAWS DETECTED IN BOND LINE AREA OR LAMINATE.



SCAN RESULTS - END (B)



SLIGHT VARIATION IN SIGNAL - NOISE AREA -

NO BOND FLAW DETECTED

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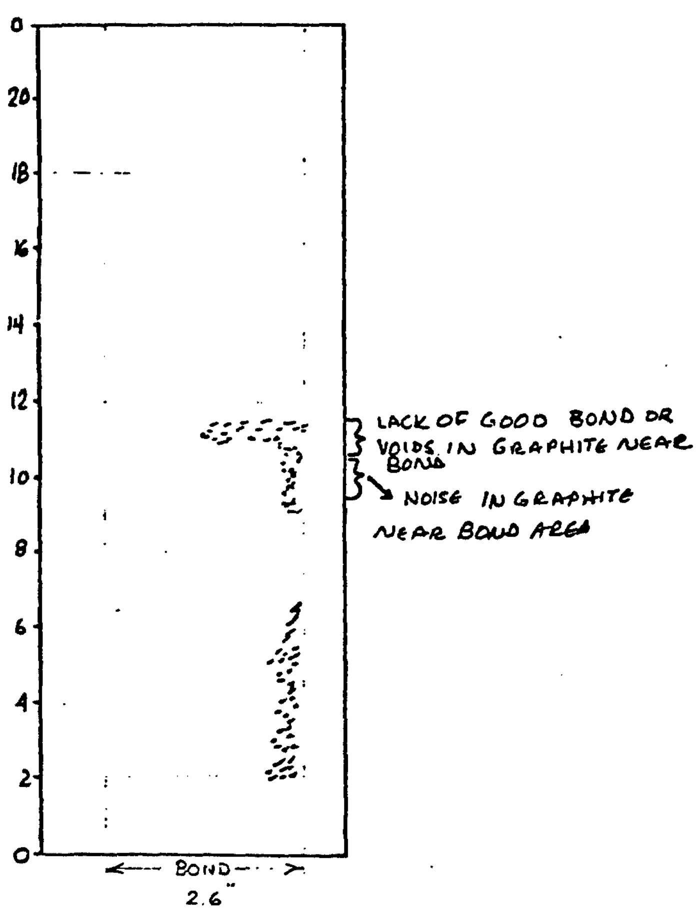
TACOM SHAFT
SCARF-JOINT C-SCAN
DATE : ____________

TUBE SN 3 XDCR TYPE (A) 0.5" 2.25mc 4"f (B) 0.6" 5mc UF MODE THRU TRANSMISSION

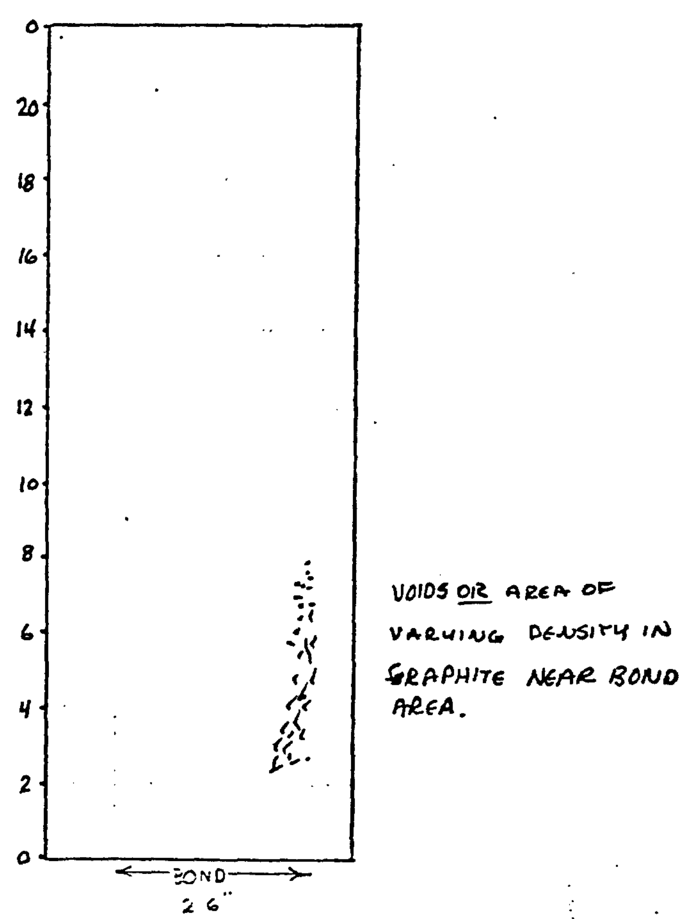
ENERGY 2 GAIN 40dB ATTEN ≃ 10 dB GATE WIDTH 10 NS GATE DELAY 45 NS

INDEX DIRECTION ________ INDEX INCR. .025 SCAN SPEED 4 IPS

SCAN RESULTS: END (A)



SCAN RESULTS - END (B)



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APPENDIX D

LEAF SPRING TEST PROCEDURE

D-1. SCOPE

This test procedure presents the requirements for laboratory testing of a leaf spring assembly under vertical loading.

D-2. APPARATUS

D-2.1 Static Load and Rate Test: The spring assembly is to be positioned in the clamped condition in a Universal Testing Machine. The front and rear lengths for the spring assembly are to be the same as these lengths in the suspension system of the vehicle.

D-2.2 Fatigue Portion of Test: The complete spring assembly is to be used for this portion of the test. It is to be clamped and set-up in an inverted position in a suitable machine at the attitude specified for vehicle installation. The suspension system brackets and/or contact supports are to be used in the test.

D-3. CONDITIONING

D-3.1 Conditioning: Condition the test specimens at 23 $\pm$ 2°C (73.4 $\pm$ 3.6°F) and 50 $\pm$ 10 percent relative humidity for not less than 40 hours prior to test.

D-3.2 Test Conditions: Conduct tests in the Standard Laboratory Atmosphere of 23 $\pm$ 2°C (73.4 $\pm$ 3.6°F) and 50 $\pm$ 10 percent relative humidity.

D-4. TEST PROCEDURE

D-4.1 Static Load and Rate Test:

D-4.1.1 The spring assembly is positioned clamped in a universal testing machine. Load spring to 2000 pounds. The torque load in each U-bolt at the clamp shall be 260 lb.-ft.

D-4.1.2 Release spring to no load position.

D-4.1.3 Compress the spring to the rated load. Rap the spring thoroughly with a mallet and record the load reading and the height.

D-4.1.4 An autographic record of load versus displacement is to be performed: this is to be a slow-speed sweep of vertical load from zero to 1.8 times the rated load and back to zero.

D-4.1.5 The clamped spring rate at the rated load shall be determined.

D-4.2 Fatigue Test

D-4.2.1 The complete spring shall be clamped and set-up in an inverted position in a suitable machine at the attitude specified for vehicle installation.

D-4.2.2 An autographic record of load versus displacement shall be made in accordance with D-4.2.7 before cyclic testing is begun.

D-4.2.3 Each sample shall be subjected to a vertical cyclic loading from 25% of the rated load (compression) to 1.8 times the rated load when clamped and shackled. Torque load on each U-bolt at the clamp shall be 260 lb.-ft.

D-4.2.4 Each sample shall be tested to failure or a maximum of 150,000 cycles.

D-4.2.5 The clamp and nuts shall be re-tightened after the initial 10,000 cycles and at least every 25,000 cycles hereafter.

D-4.2.6 The test speed shall be 25-110 CPM.

D-4.2.7 Before cycling and after every 25,000 cycles, an autographic record of load versus displacement shall be performed. This is to be a slow-speed sweep of vertical load from zero to 1.8 times the rated load and back to zero. The clamped spring rate at the rated load shall be determined.

D-5. CALCULATIONS

D-5.1 Calculate the spring rate at the required load from the load-displacement curve:

$$K = \frac{P}{S}$$

where

K = spring rate

$\frac{P}{S}$ = slope of the load-displacement curve at the required load

D-6. REPORT

D-6.1 The report shall include the following:

D-6.1.1 Sample identification and fatigue life determined for each assembly.

D-6.1.2 The autographic records of load versus displacement recorded during the rate test.

D-6.1.3 The spring rates calculated as required.

D-6.1.4 Looseness of U-bolts at clamp.

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